Universidade de Aveiro Departamento de Biologia
2013

Sara Isabel Ferreira Marques

OPÇÕES DOS MAMÍFEROS NA PAISAGEM HETEROGÉNEA DO BAIXO VOUGA LAGUNAR

MAMMAL CHOICES IN HETEROGENEOUS LANDSCAPE OF THE BAIXO VOUGA LAGUNAR

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Biologia Aplicada ramo “Ecologia, Biodiversidade e Gestão de Ecossistemas”, realizada sob a orientação científica do Doutor Carlos Manuel Martins Santos Fonseca, Professor auxiliar com agregação do Departamento de Biologia da Universidade de Aveiro e coorientação do Doutor Joaquim Pedro Ferreira, investigador de Pós-Doutoramento do Centro de Estudos do Ambiente e do Mar da Universidade de Aveiro e da Doutora Rita Gomes Rocha, investigadora de Pós-Doutoramento do Centro de estudos do Ambiente e do Mar da Universidade de Aveiro.

Ao Eduardo, por tudo e por tanto!

"Inspiration's what you are to me
Inspiration, look and see
And so today, my world it smiles
Your hand in mine, we walk the miles
Thanks to you it will be done
For you to me are the only one"
from "Thank you" of Led Zeppelin

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palavras-chave

carnívoros, galeria rípicola, micromamíferos, modelação ecológica, paisagem heterogénea, predador-presa, recursos, zona húmida

resumo

A relação entre a estrutura da paisagem e a distribuição das espécies é um dos temas centrais da ecologia da paisagem. Os mamíferos terrestres são particularmente suscetíveis às características físicas do ambiente, como o tipo de habitat e a complexidade da paisagem, assim como à disponibilidade de recursos (e.g. abrigo e alimento). O principal objetivo deste estudo centrou-se na descrição e compreensão dos padrões de distribuição, abundância e riqueza específica dos mamíferos terrestres na paisagem heterogénea do Baixo Vouga Lagunar. Para tal foi amostrada a comunidade de micromamíferos e carnívoros com recurso a três metodologias distintas: programa de captura de micromamíferos (Rodentia e Eulipotyphla), e prospeção de indícios de presença e armadilhagem fotográfica de carnívoros. No geral, os resultados mostraram que os habitats húmidos, como os caniçais, juncais e sapais, favorecem a fauna de micromamíferos, sendo o caniçal o habitat que registou valores mais elevados de diversidade. Para além disso, a riqueza específica de carnívoros evidenciou ser favorecida pelo comprimento das linhas de água doce, e consequentemente pela vegetação ripícola associada. Pelo contrário, a floresta exótica composta por eucaliptos apareceu negativamente correlacionada com ambos os grupos de mamíferos, apresentando os valores mais baixos de riqueza específica de micromamíferos. As características da paisagem mostraram ser o fator mais importante para a riqueza de carnívoros, quando comparadas com a disponibilidade de presas e influência humana, ou com a combinação destes. Surpreendentemente, a disponibilidade de presas não influenciou a riqueza de carnívoros, o que pode ser uma consequência da ampla disponibilidade espacial de micromamíferos pela matriz da paisagem. Embora a uma pequena escala a heterogeneidade da paisagem pareça não influenciar a abundância de micromamíferos, à escala da paisagem o mosaico de habitats parece promover a diversidade de micromamíferos. Esta conclusão assenta sobre a distribuição das diversas espécies que varia pelas manchas de diferentes habitats. Por outro lado, a riqueza específica de carnívoros foi negativamente influenciada pela heterogeneidade e fragmentação da paisagem, a qual é composta maioritariamente por habitats abertos. Os principais resultados deste estudo suportam a importância dos habitats lineares para a comunidade de carnívoros no Baixo Vouga Lagunar, nomeadamente a galeria ripícola, e dos habitats húmidos para a fauna de micromamíferos, que lhes fornecem alimento. Revelaram ainda o reduzido valor biológico das monoculturas, em particular florestas de espécies exóticas. Este estudo reforça assim importância do Baixo Vouga Lagunar para a vida selvagem, e fornece bases essenciais para o desenvolvimento de medidas adequadas de gestão e conservação para a região.

keywords

carnivores, ecological modelling, landscape heterogeneity, predator-prey, resources, riparian habitat, small mammals, wetland

abstract

The relation between landscape structure and species distribution is a major question in landscape ecology. Terrestrial mammals are particularly susceptible to the spatial features, such as habitat type and landscape complexity, as well as to resource availability (e.g. shelter and food supply). The main objective of this thesis was to describe and understand the patterns of terrestrial non-volant mammal species richness, distribution and abundance in the heterogeneous landscape of Baixo Vouga Lagunar, north-western Portugal. Thus, small mammals and carnivores were sampled using three different strategies: a capture programme focused on small mammals (Rodentia and Eulipotyphla), and sign surveys and camera trapping for carnivores. In general, wetland habitats, such as reed beds, rushes and marshlands, seemed to favour small mammal fauna, being reed bed the habitat with the highest values of diversity. Furthermore, carnivore richness appeared to be favoured by the length of freshwater lines, and consequently by the associated riparian vegetation. Contrary, exotic forest was negatively related to both small mammal fauna and carnivore richness, and presented the lowest small mammal diversity. Overall, carnivore richness was mainly driven by landscape features, rather than by human influence and prey availability, or a combination of them. Surprisingly, prey availability seemed not to influence carnivore richness, probably as a consequence of a spatiallly wide availability of small mammals through the landscape matrix. Although at a fine-scale of the landscape, heterogeneity did not seem to influence the abundance of small mammals, at a broad-scale, the landscape matrix seems to promote small mammal diversity, since species distribution fluctuated throughout the patchy landscape. Contrasting, carnivore richness was negatively influenced by landscape heterogeneity and fragmentation, since the landscape is mainly composed by open habitats. Overall, the main findings of this study support the importance of hedgerow habitats (e.g. riparian gallery) to carnivore assemblage by providing water, shelter and enhancing landscape connectivity, and of wetland habitats for small mammal community. Furthermore, the results obtained revealed the reduced biological value of monocultures, especially forests of exotic species. This study reinforces the importance of the Baixo Vouga Lagunar region to wildlife and provides crucial information to develop adequate management and conservation guidelines.

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Chapter 1

GENERAL INTRODUCTION

1. GENERAL INTRODUCTION

1.1 HETEROGENEOUS LANDSCAPE AND TERRESTRIAL MAMMALS

Mediterranean ecosystems are a typical mosaic of landscape patches, where the traditional rural landscapes are characterized by multi-use systems. These complex landscapes with natural and managed habitats have been shaped along centuries by human activities (e.g. Caraveli, 2000; Pinto-Correia, 2000; Tousignant et al., 2010; Gomes et al., 2011; Salvati et al., 2012) and natural disturbance regimes (e.g. Clavero et al., 2004; Boix et al., 2005). The result of this dynamism is a complex spatial arrangement of urban areas, agricultural and silvicultural crops, and pastoral production lands combined with remnants of natural habitats (Rosalino et al., 2009; Pereira et al., 2012).

The landscape heterogeneity may provide a sustainable use of natural and man-made resources by wildlife dependent on these environments (e.g. Pita et al., 2009). Resource availability, as food and shelter, is an essential factor for the development, functioning and maintenance of organisms, and also influences population dynamics (Virgós and Casanovas, 1999; Rosalino et al., 2005; Mortelliti and Boitani, 2008). However, differences in the productivity and structural complexity of vegetation between habitats promote fluctuations in resource availability within certain landscape compartments, which may influence the habitat suitability for organisms (e.g. Sarmento et al., 2010). The result is a landscape matrix with mosaics of optimal and sub-optimal habitats (Santos et al., 2007; Rosalino et al., 2009; Van der Valk and Warner, 2009). In general, in a heterogeneous environment, with potentially higher number of available niches, the adaptation to different types of available resources may promote the coexistence of a diverse group of taxa, enhancing the diversity at those sites (habitat heterogeneity hypothesis – MacArthur and MacArthur, 1961; Sponchiado et al., 2012).

Nevertheless, when studying the interaction between wildlife and heterogeneous landscapes, it is important to consider the scale at which this analysis is carried on and the target species-group. Ecological effects of habitat heterogeneity may vary considerably between mammal-groups depending of their habitat perception, since different species with distinct ecological characteristics have home ranges with various extensions. Concerning Iberian mammals, a home range of small mammal species rarely exceed 4 ha (e.g. *Apodemus sylvaticus* – Rosalino et al., 2011), while home range of

predator species as mammalian carnivores, can reach approximately 500 ha (e.g. *Vulpes vulpes* – Cavallini and Lovari, 1994). In the former species, each patch can contain home ranges of one or more individuals; while for the latter, a functional home range of an individual can contain various fragments of the landscape matrix. Additionally, at a given site with a certain set of resources and climatic parameters, each species could be influenced differently by these variables, because organisms differ in their ability to utilize various resources and in their response to climatic parameters (Sainz-Elipe et al., 2012). Hence, variability in habitat patch characteristics can induce different animal responses and consequently, induce community changes across the landscape.coexistence of a diverse group of taxa, enhancing the diversity at those sites (habitat heterogeneity hypothesis – MacArthur and MacArthur, 1961; Sponchiado et al., 2012).

Nevertheless, when studying the interaction between wildlife and heterogeneous landscapes, it is important to consider the scale at which this analysis is carried on and the target species-group. Ecological effects of habitat heterogeneity may vary considerably between mammal-groups depending of their habitat perception, since different species with distinct ecological characteristics have home ranges with various extensions. Concerning Iberian mammals, a home range of small mammal species rarely exceed 4 ha (e.g. *Apodemus sylvaticus* – Rosalino et al., 2011), while home range of predator species as mammalian carnivores, can reach approximately 500 ha (e.g. *Vulpes vulpes* – Cavallini and Lovari, 1994). In the former species, each patch can contain home ranges of one or more individuals; while for the latter, a functional home range of an individual can contain various fragments of the landscape matrix. Additionally, at a given site with a certain set of resources and climatic parameters, each species could be influenced differently by these variables, because organisms differ in their ability to utilize various resources and in their response to climatic parameters (Sainz-Elipe et al., 2012). Hence, variability in habitat patch characteristics can induce different animal responses and consequently, induce community changes across the landscape.

In general, community assemblages of terrestrial mammals vary spatially and temporally (Montgomery, 1989; Lodé, 1994; Scott et al., 2008). They are greatly affected by heterogeneous environments, quality of matrix and connectivity or surrounding land-use type (Delattre et al., 1996; Virgós, 2001; Virgós and García, 2002; Clavero et al., 2004; Scott et al., 2008; Rosalino et al., 2009).

Small mammals occur in a wide range of habitats (e.g. Gray et al., 1998; Khidas et al., 2002; Pearce and Venier, 2005; Scott et al., 2008; Gomes et al., 2011; Fischer et al., 2011; Ascensão et al., 2012), which selection is strongly influenced by environmental

factors, such as food and shelter availability, that are crucial to reproduction and survival (Hansson, 1977, 1982; Angelstam et al., 1987; Hansson, 1997; Ecke et al., 2001; Jensen et al., 2003). Landscape structure may also influence and shape small mammal communities, and these relationships are also modulated by seasonal effects (Fischer et al., 2012). In fact, small mammal abundance and diversity are related to climate conditions, such as temperature and rainfall, which dictate patterns of distribution and temporal variation (Torre et al., 1996; Corominas, 1999; Ernest et al., 2000).

Small mammal fluctuations are recognized as important factors for maintenance of natural equilibrium (Tapper, 1979; Pearce and Venier, 2005) since small mammals (Muridae and Soricidae) have a crucial role in ecosystems and food webs (Golley, 1960; Erlinge et al., 1983; Sieg, 1987). They are primary and secondary consumers, feeding on various seeds, plants, lichen, fungi and invertebrates (Watts, 1968; Sieg, 1987; Montgomery and Montgomery, 1990). Thus playing an important role in seed dispersal, weed seed removal, which may potentially influence vegetation composition via selective foraging, and controlling invertebrates (Sieg, 1987; Brown and Hesk, 1990; Baraibar et al., 2009). Further, small mammals are an important component in the diet of many Mediterranean carnivores (e.g. Lodé, 1997; Virgós et al., 1999; Rosalino and Santos-Reis, 2002). Hence, as key organisms in the trophic chain, variations in their abundance and distribution can exert a significant influence on predator population fluctuations (Tapper, 1979; Karanth et al., 2004; Mortelliti and Boitani, 2008).

In southern Europe, carnivore habitat use often is a result of habitat-specific distribution and availability of principal prey, due to the resource limitations imposed by Mediterranean ecosystems (e.g. Lodé, 1994; Cavallini and Volpi, 1996; Santos et al., 2007; Mortelliti and Boitani, 2008; Šálek et al., 2010; Svobodová et al., 2011; Červinka et al., 2013). In a heterogeneous and fragmented landscape, within certain limits of patch size and isolation, an increase of food supply could enhance probability of carnivore presence in patch (Mortelliti and Boitani, 2008). Generalist carnivores are often favoured by landscape complexity (e.g. Constible et al., 2006; Pita et al., 2009; Pereira et al., 2012). Indeed, many of the species inhabiting in the Mediterranean ecosystems are widespread and described as generalists species, being able to adapt to various habitats (Aulagnier et al., 2009). Their distribution and abundance may have important implications on the ecosystem structure and functioning since small and medium carnivores often play fundamental roles in natural processes and in the ecological equilibrium by maintaining healthy populations of prey species, and avoiding overpopulation of undesirable species (Erlinge et al., 1983). Moreover, carnivores may contribute to the improvement of quality,

conservation and regeneration of flora by controlling several herbivore populations and acting as seed dispersers (Rosalino et al., 2010).

This study investigated spatial and temporal dynamics of small mammals, and distribution patterns of carnivores on the coastal wetland landscape of Baixo Vouga Lagunar (BVL), north-western Portugal. This region is considered one of the most biologically rich wetlands in Europe, supporting internationally important numbers of rare bird and plant species (Brito et al., 2010). Previous studies in this region focused mainly on birds (Teixeira, 1981; Fernandes, 1998; Neto, 2003; Brito and Pereira, 2006; Marques and Ramos, 2006); however there were no studies about mammals in BVL. Hence, this work intends to complete a gap in knowledge about the processes that shape the distribution and richness of small mammals and carnivores within this human-altered heterogeneous landscape. This is a particularly important study since investigated two groups of organisms belonging to different links of the food chain (small mammals are primary and secondary consumers and prey of many Mediterranean carnivores, while mammalian carnivores are species at the highest levels of food chains).

1.2 FRAMEWORK

The present study is included in a broader project named “Factors that affect the seasonal and spatial patterns of vertebrate diversity and activity in different habitat types of the humanized landscape of Baixo Vouga Lagunar”, developed by a team of MSc students, under the scientific orientation of PhD and Postdoctoral researchers of the Wildlife Research Unit, Department of Biology, Centre for Environmental and Marine Studies, University of Aveiro (Figure 1.1). This project arises from the need to understand the spatial and seasonal patterns of the distribution of species that occur in the humanized landscape of BVL, as well as to determine which are the factors influencing them.

This region, holder of a great biological diversity, is characterized by a mosaic landscape, with aquatic and terrestrial environments, and a great habitat diversity, largely shaped by the secular human action (Brito et al., 2010). However, knowledge about the dynamics of the animal populations, assemblages and communities that occur in the region is still very scarce.

This project intends to bridge this gap in the scientific knowledge, by investigating a patterns and processes of diversity and abundance of a wide variety of vertebrate and

invertebrate taxa, belonging to several trophic levels, namely insects, amphibians, small non-volant mammals, bats, carnivores and birds.

The scheduling of the several fieldwork components, relative to the different studied taxonomic groups, took into account an optimization effort regarding human, material and financial resources, through the mutual help of the team members.

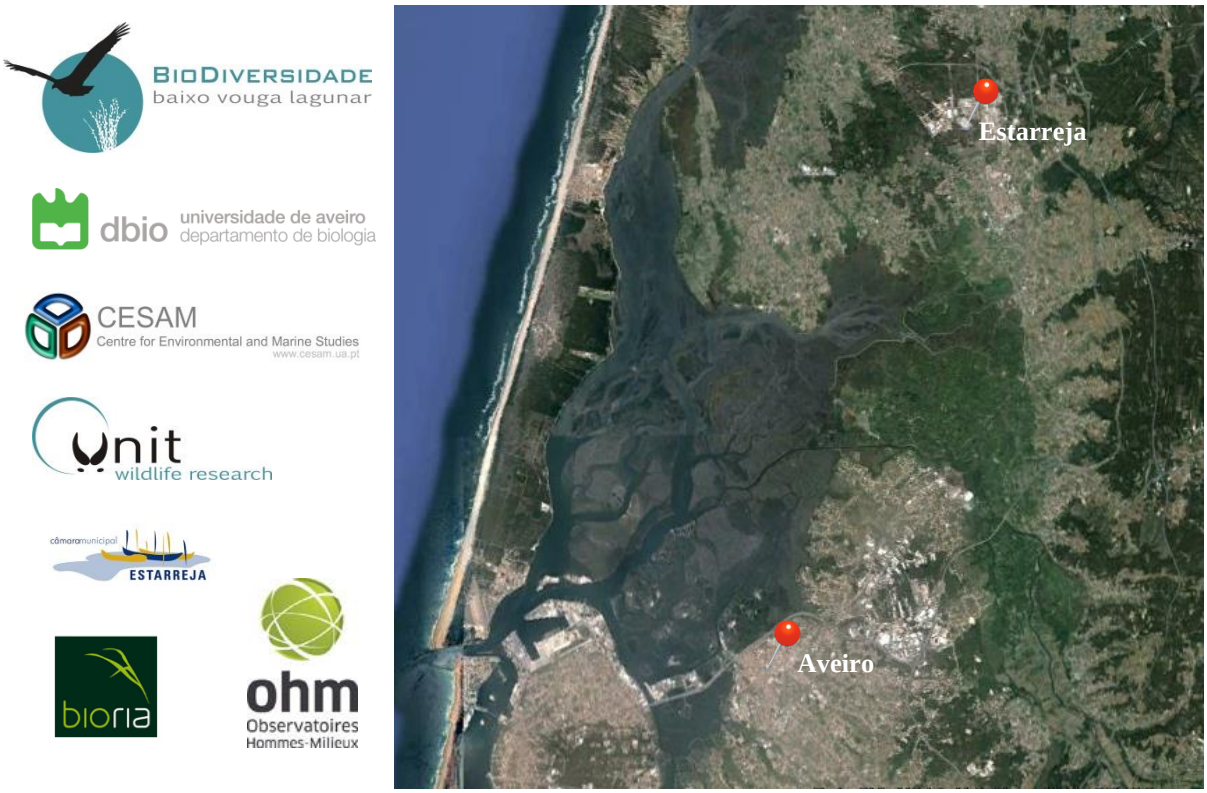

Figure 1.1 Satellite image of the region, institutions responsible for co-funding of the project (Municipality of Estarreja[1] and Observatoires Hommes-Millieux[2]) and institutions involved in the BVL project located in Estarreja (BioRia[3]) and Aveiro (University of Aveiro – Department of Biology[4], CESAM[5], and Wildlife Research Unit[6])

[1] http://www.cm-estarreja.pt/
[2] http://www.ohm-inee.cnrs.fr/
[3] http://www.bioria.com/
[4] http://www.ua.pt/dbio/
[5] http://www.cesam.ua.pt/
[6] https://sites.google.com/site/unidadevidaselvagem/

The main objectives of the project, transversal to all the studies are:

i) To detect spatial patterns of diversity within the mosaic of habitats of the region;

ii) To assess the existence of seasonal patterns in the occupation of the different habitats, by the various taxa under study;

iii) To identify the main factors behind those patterns, relating species presence with biotic, abiotic and anthropogenic variables.

Based on the scientific knowledge already acquired and to be acquired in the future, and by the means of ecological modelling approaches, the elaboration of maps of priority conservation and management areas is also intended. This will allow the proposal of very specific management actions.

This project will be used as groundwork for future ecological research in the BVL area by the Wildlife Research Unit team, as well as to a more sustainable exploration and management of its natural resources, by giving continuity to established partnerships (e.g. Municipality of Estarreja) and searching for new ones with the local stakeholders.

Three other MSc theses resulted from this project. The specific goals and main results obtained in each one are as follows:

"Factors affecting the diversity of amphibians in Baixo Vouga Lagunar"

Globally, the main objectives of this study, developed by Inês Torres, were to understand which factors determine the distribution and diversity of amphibians within the heterogeneous landscape of Baixo Vouga Lagunar. Amphibians' sampling was conducted in three replicates of seven habitat types representative of the study area: *Bocage*, rice fields, maize fields, marshland, reed beds, sea rushes and forest. Several methodologies were applied simultaneously, and in a standardised way. Additionally, prey abundance was assessed by using light traps to sample insects. 12 different species of amphibians were identified, corresponding to approximately 70% of the species occurring in Portugal. As expected, prey availability was one of the most important factors behind the community composition of these animals. Furthermore, the distance to wells was found to be the best predictor for amphibians richness, underlining the importance of those structures within an agriculture-dominated landscape such as Baixo Vouga Lagunar.

"Foraging and spatial ecology of Marsh harrier in Baixo Vouga Lagunar"

The study of the bird of prey Circus aeruginosus, developed by Michelle Alves, aimed to investigate the species preferences of habitats and prey, as well as the factors that determine its occurrence and abundance. Sampling was conducted through direct observation of the individuals, in fixed points within the study area, in a daily sampling throughout an annual cycle. Regurgitations and prey remaining were collected, so the diet of the species could be assessed. The results obtained revealed a diverse diet, that included small mammals, birds, reptiles, insects and eggs. However, a clear preference and selection towards Microtus sp. was found. Besides prey availability, natural habitats such as reed beds and marshlands were found to be positively associated with species presence and abundance within the Baixo Vouga Lagunar landscape.

"Bat diversity and activity in the mosaic of Baixo Vouga Lagunar"

The study of bat assemblages, developed by Eduardo Mendes, was based on the acoustic sampling of bats, as well as the sampling of nocturnal insects using light traps. Globally, this study aimed to determine wich factors affect bat diversity and actividy within the heterogeneous landscape of BVL. Sampling was carried out for an year, in three replicates of eight habitat types characteristic of the region (rice field, *Bocage*, reed bed, forest, sea rush, maize field, marshland and urban), sampled twice a month. Walking transects were performed, using an ultrasound detector and a digital sound recorder, which enables the detection of echolocation pulses, and its storage for posterior identification. During bat sampling, performed on the first hours after sunset, light traps were set in the field to evaluate prey availability. Captured insects were collected and storage for posterior identification in the laboratory. Overall, the main findings indicated that bats exploit all of the BVL habitats, and that the mosaic landscape provides them several opportunities, which present strong seasonal ans spatial dynamics. Furthermore, the results obtained suggest that bats are sensitive to local resources availability and distribution while simultaneously reacting to broader landscape features.

"Mammal choices in the heterogeneous landscape of Baixo Vouga Lagunar"

The study of the terrestrial non-volant mammals, developed by me, addresses the predator-prey interaction, being use several different methodologies for the investigation of small mammals and carnivores. Detailed information on the specific objectives, methods and results will be the theme of this thesis.

1.3 OBJECTIVES

The main goal of this study was to describe and understand patterns of terrestrial non-volant mammal species richness (small mammals and carnviores) and abundance (small mammals) in the heterogeneous landscape of the BVL.

Regarding small mammals, this study investigated the spatial and temporal dynamics of their abundance and richness in the study area. For that, several landscape characteristics were evaluated, differences in land cover type assessed, and climate conditions recorded during small mammal sampling, in order to:

i) determine which biotic and abiotic factors, namely landscape characteristics and climate conditions, significantly affect small mammal abundance and species richness in a high diverse landscape matrix; and,

ii) understand the influence of the landscape heterogeneity on small mammal abundance and richness.

Concerning the mammalian carnivores, this study also investigated the abiotic and biotic factors that influence carnivore richness in the study area. Specifically, the main aims of this study are:

i) to determine which type of factors, namely landscape features, human influence and/or prey availability (or combination of these factors) affect the carnivore richness; and,

ii) to identify keystone structures and/or limiting resources for the carnivore assemblage within the landscape matrix.

Results will enable a better integration of the requirements of small mammals and carnivores into wetland and heterogeneous landscapes conservation and management.

1.4 THESIS STRUCTURE

The present thesis is organized in five main chapters. The first chapter (Chapter 1) presents a general introduction about the theme of this thesis, the framework in which this study is included, and the main aims for both groups studied. The second chapter (Chapter 2) is devoted to the detailed description of several features of the study area. The two following chapters (Chapters 3 and 4) are in the format of scientific articles and answer to research questions. Specifically, the third chapter (Chapter 3), intituled "Influence of landscape heterogeneity on small mammals in a coastal wetland system, NW Portugal", is focused on investigation of the spatial and temporal dynamics of small mammal abundance and richness in the study area. And the fourth chapter (Chapter 4), intituled "Influence of human, prey availability and landscape features on carnivore richness in a heterogeneous coastal wetland, NW Portugal", investigated the abiotic and biotic factors (landscape features, human influence and prey availability) that influence carnivore richness in the landscape matrix of BVL. These papers treat different organisms but complement each other, being included small mammal data from Chapter 3 in the Chapter 4, considered as prey availability of carnivores. The standard format presented in each varies according to the standard rules of the journal in which the articles are intended to be submit. The final chapter (Chapter 5) presents the summary and general discussion of main findings of this research. Due to this structure some repetition may occur. The literature cited in each chapter is provided separately.

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Chapter 2

STUDY AREA

2. STUDY AREA

2.1 LOCATION

The study was conducted in an, approximately, 13,000 ha area of north-western Portugal (40º4''N, 8º33'-8º40'W), located in the Aveiro district, which included part of the Baixo Vouga Lagunar (BVL) (Figure 2.1). To the south the study area is limited by the Vouga River and to the west by an estuarine coastal lagoon (Ria de Aveiro). This area encompasses territories of five municipalities (Albergaria-a-Velha, Aveiro, Estarreja, Murtosa and Ovar) (Figure 2.1), and a special protection area (SPA) of the Ria de Aveiro coastal lagoon, under the Birds Directive (79/409/EEC).

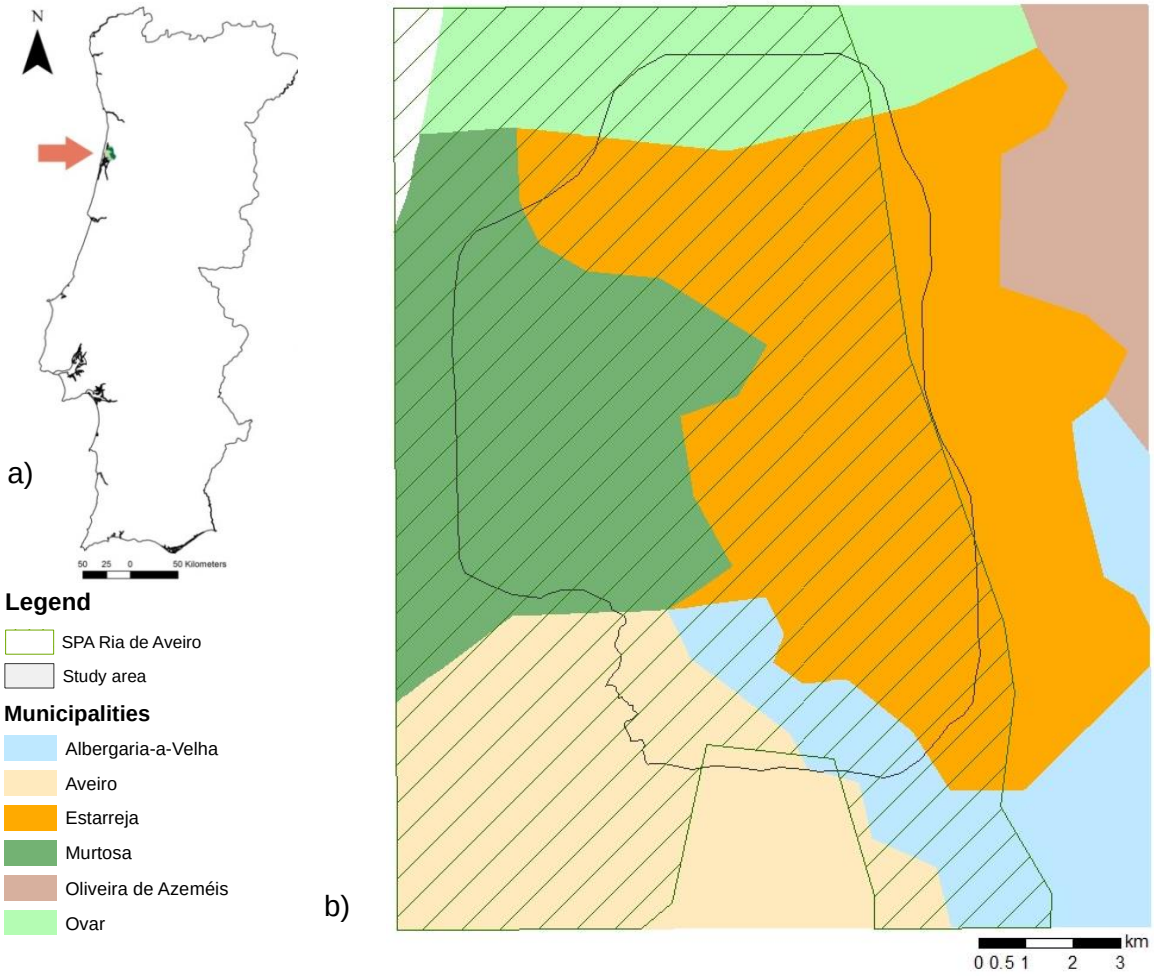

Figure 2.1 a) Location of the study area in mainland Portugal; b) Limits of municipalities in the study area. Adapted from "Atlas do Ambiente Digital" (APA, 1998)

2.2 LAND COVER

The typical man made landscape and the strong interrelation between agriculture and nature, give this region very particular characteristics (Brito et al., 2010). This region is characterized by a highly heterogeneous and complex landscape structure, dominated by agricultural crops, mainly maize fields (Table 2.1 and Figure 2.2). Maize fields are temporary crop fields of maize (*Zea mays*). This habitat has the particularity of not exhibit constant characteristics throughout the whole year, since it is a temporary culture. There are also rice fields that are flooded fields dedicated to rice culture (*Oryza* sp.).

This region is dominated by open environments with a dense network of brackish-water channels originated in a coastal lagoon, Ria de Aveiro. One particularity of this complex wetland system is the occurrence of various transition habitats between terrestrial ecosystems and saltwater, such as marshlands, rushes and reed beds (Table 2.1). Marshland is a low-lying wetland with halophyte vegetation, mainly dominated by *Spartina maritima*, *Salicornia ramosissima*, *Sarcocornia perennis* and *Halimione portucaloides*. Rush is a natural habitat with large extensions of the common sea rush (*Juncus maritimus*). Reed bed is a natural habitat characterized by large extensions of common reed (*Phragmites australis*), where the influence of saline water is limited (Teixeira, 1981).

Woody habitats in the study area are composed by *Bocage*, riparian gallery and forest (Table 2.1). The *Bocage* is a mosaic landscape composed of agricultural and pastures fields, usually small, separated by live fences of autochthonous trees (e.g. *Alnus glutinosa*, *Salix atrocinerea*, *Quercus robur*), shrub and herb hedgerows (e.g. *Hedera* sp., *Rubus* sp.), which joins a dense network of narrow waterways. The riparian gallery is a linear habitat adjacent to inland aquatic systems, composed mainly by autochthonous woody vegetation (e.g. *Alnus glutinosa*, *Salix atrocinera*). The forest present in the study area is manly dominated by eucalyptus monocultures (*Eucalyptus* sp.).

This region is therefore characterized by a high degree of heterogeneity and spatial complexity, which are often linked to higher resource availability and thus, to greater biodiversity (Bazzaz, 1975; Brito et al., 2010).

Table 2.1 Habitat cover (area, percentage and number of patches) in the study area (≈13,000 ha), Baixo Vouga Lagunar. Habitats are classified as "open habitat" and "woody habitat"

Habitat	Area (ha)	Area (%)	Patch number	Mean area patch (ha)	Open habitat	Woody habitat
Bocage	944.85	7.32	6	59.65		✓
Fallow land	291.26	2.26	21	13.87	✓	
Forest	2030.72	15.74	92	22.07		✓
Marshland	1617.21	12.54	26	62.20	✓	
Reed bed	549.51	4.26	9	61.06	✓	
Riparian gallery	14.71	0.11	2	7.36		✓
Rush	813.97	6.31	16	50.87	✓	
Coastal water	1190.52	9.23	1	1190.52	✓	
Rivers	19.36	0.15	1	19.36	✓	
Maize field	3816.14	29.58	108	35.33	✓	
Rice field	119.30	0.92	2	157.48	✓	
Urban	1491.49	11.56	175	8.52	✓	

2.3 CLIMATE

The study area is a transition region between Atlantic and Mediterranean climates (Costa et al., 1998). Deeply influenced by the Atlantic Ocean, the BVL climate is characterized by mild temperatures, low temperature ranges and high levels of humidity (Costa et al., 1998; Pinho et al., 2003; Bonmati et al., 2006). With mild winters and dry summers, the mean annual temperature was 14.5ºC, with a maximum temperature of 36.2ºC in July'12 and minimum of -2.0ºC in February'12 (data from CUF® weather station). The annual accumulative rainfall was 627.6 mm, which occurred mainly between October and December, and in April (data from CESAMET, 2011-2012).

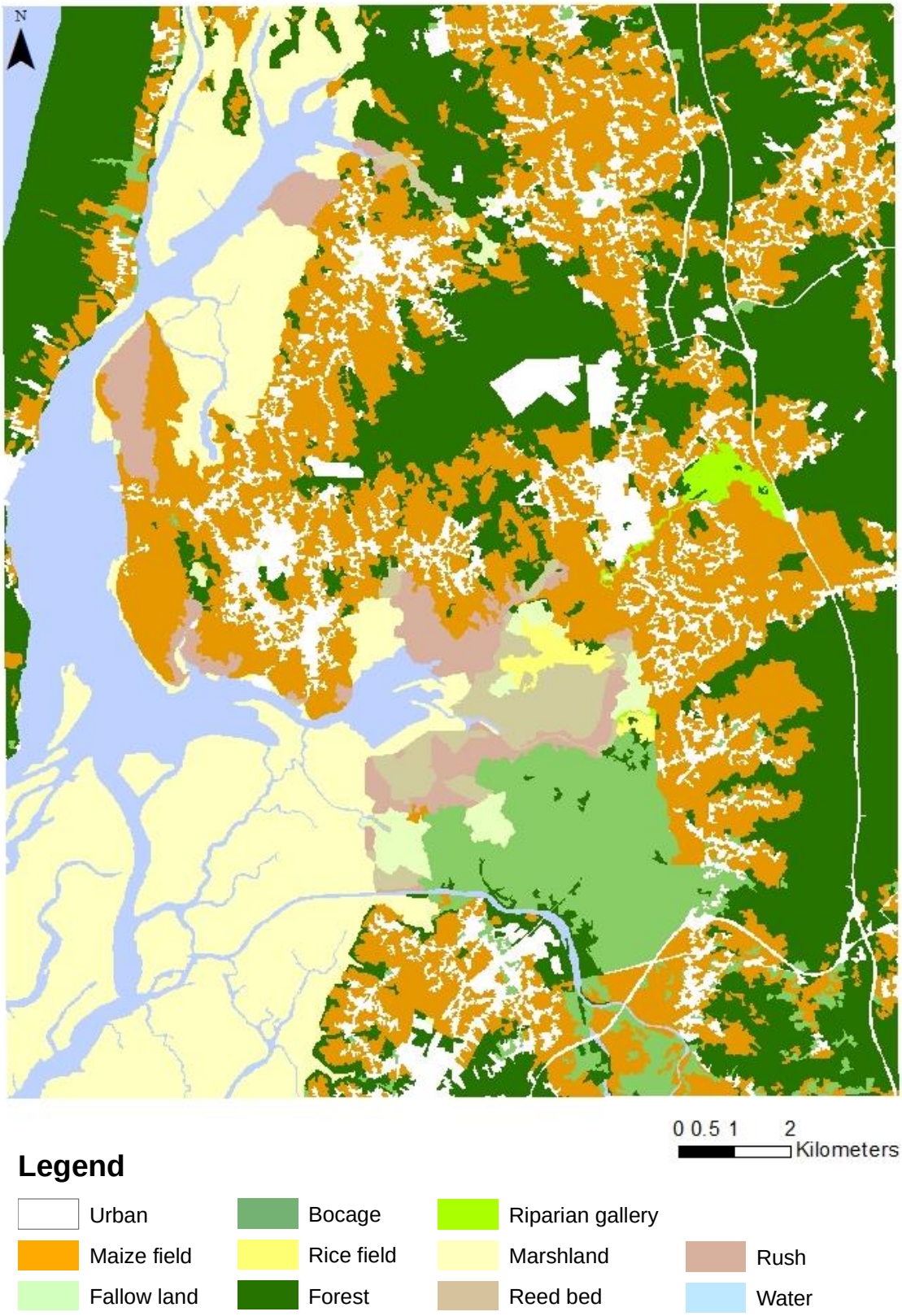

Figure 2.2 Land cover in the study area. Adapted from "Cos'2007" (IGP, 2010)

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Chapter 3

INFLUENCE OF LANDSCAPE HETEROGENEITY ON SMALL MAMMALS IN A COASTAL WETLAND SYSTEM, NW PORTUGAL

3. INFLUENCE OF LANDSCAPE HETEROGENEITY ON SMALL MAMMALS IN A COASTAL WETLAND SYSTEM, NW PORTUGAL

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3.1 ABSTRACT

The abundance and distribution of small mammals are important factors for ecosystem structure and functioning, which are often affected by spatial heterogeneity and temporal fluctuations. In this study, we assessed the spatial and temporal dynamics of small mammals in a heterogeneous coastal wetland landscape. More specifically, we tested the influence of habitat type, landscape composition and climate conditions on small mammal relative abundance and species richness in Baixo Vouga Lagunar, north-western Portugal. Seven different habitats (Bocage, forest, maize fields, marshland, reed beds, rice fields and rushes) were sampled every two months, between November 2011 and October 2012 (a trapping effort of 18,665 trap-nights). We recorded a total of 1,961 captures, including 566 recaptures, of which 1,714 (87.4%) were rodents and 247 (12.6%) were shrews. Spatially, reed beds presented the highest values of small mammal diversity and favoured small mammal fauna, as well as rushes and marshlands. In contrast, Bocage and forest did not favour most of the small mammal fauna, with forest being the habitat with the lowest diversity. In general, cumulative precipitation favoured the abundance of most species, determining small mammal temporal fluctuations. At a fine-

scale, landscape heterogeneity did not seem to influence small mammal abundance. However, at a broader scale, the landscape matrix appeared to promote small mammal fauna, since species distributions fluctuated throughout the patchy landscape, highlighting the importance of wetland ecosystems to small mammal populations and communities. Nevertheless, conservation and management efforts in the patchy BVL landscape will often need to consider features of the surrounding landscape.

Keywords Baixo Vouga Lagunar, ecological modelling, heterogeneous landscape, rodents, shrews, wetland

3.2 INTRODUCTION

The relationship between landscape structure and species distribution is a major question in landscape ecology (Thornton et al., 2011). Several studies on small mammal communities have investigated their temporal fluctuations and spatial distributions at habitat and ecosystem levels (Delattre et al., 1996; Khidas et al., 2002; Loman, 2008; Scott et al., 2008; Fischer et al., 2012). Their abundance and distribution are recognised as important factors for ecosystem structure and functioning (Tapper, 1979; Pearce and Venier, 2005).

Small mammals (Muridae and Soricidae) have a crucial role in ecosystems and food webs (Golley, 1960; Erlinge et al., 1983; Sieg, 1987), acting as primary and secondary consumers, feeding on various seeds, plants, lichen, fungi and invertebrates (Watts, 1968; Sieg, 1987; Montgomery and Montgomery, 1990). Therefore, they play an important role in seed dispersal, weed seed removal (which may potentially influence vegetation composition via selective foraging), and controlling invertebrates (Sieg, 1987; Brown and Hesk, 1990; Baraibar et al., 2009). Furthermore, small mammals are also an important food source for many carnivorous mammals and birds of prey (e.g. Virgós et al., 1999; Schmidt et al., 2002; Askew et al., 2007). Hence, as key organisms in the trophic chain, variations in their distribution and abundance can influence the population dynamics of both prey and predators (Tapper, 1979; Erlinge et al., 1983; Salamolard et al., 2000; Meunier et al., 2000; Mortelliti and Boitani, 2008).

Occurring in a wide range of habitats (e.g. Khidas et al., 2002; Pearce and Venier, 2005; Scott et al., 2008; Gomes et al., 2011; Fischer et al., 2011), small mammal presence and abundance is strongly influenced by environmental factors such as food

and shelter availability, which are crucial to their reproduction and survival (Hansson, 1979, 1982; Angelstam et al., 1987; Jensen et al., 2003). Other environmental factors, such as vegetation structure, habitat type, landscape composition and connectivity, also affect small mammal dynamics (Tew et al., 2000; Ecke et al., 2001, 2002; Wijnhoven et al., 2005).

Nevertheless, similar habitat types in different locations can present different small mammal population densities, which may be one consequence of the “landscape effect” (Delattre et al., 1996; Silva et al., 2005). In fact, landscape features may have impacts on small mammal populations and communities (e.g. Fischer et al., 2012). For instance, land cover surrounding a particular habitat may play an important role in localised small mammal abundance and diversity (Silva et al., 2005). Generally, heterogeneous environments have a positive influence on small mammal abundance and richness (Kerr and Packer, 1997; Ecke et al., 2002; Fischer et al., 2011). In these environments with a potentially higher number of available niches, adaptation to different types of available resources may promote the co-existence of a diverse group of taxa, enhancing the diversity at those sites (Sponchiado et al., 2012). The spatial arrangement of habitats in a given environment with greater structural complexity may affect population dynamics, since small mammal densities reflect the suitability of the habitat for each species (Hansson, 1977, 1982, 1997; Loman, 2008). Thus, the diversity in a landscape matrix and habitat type availability may determine species presence and persistence (Scott et al., 2008; Sponchiado et al., 2012).

Small mammal populations and community structure are also affected by temporal variations (Huitu et al., 2003; Monadjem and Perrin, 2003; Fischer et al., 2012). Climate variables, such as temperature and rainfall, establish patterns of distribution and seasonal variation for most species (Torre et al., 1996; Corominas, 1999; Ernest et al., 2000). In particular, rainfall is used by ecologists as a measure of productivity (Mittelbach et al., 2001) and has been used to interpret seasonal changes in food resources for small mammals (Ernest et al., 2000; Milstead et al., 2007).

Wetlands are among the most productive ecosystems in the world (Zedler and Kercher, 2005; Mitsch and Gosselink, 2007), and are of international conservation importance for the biological diversity they harbour, including small mammals (e.g. Martin et al., 1991; Jude and Pappas, 1992; Silvestri et al., 2005; Horváth et al., 2011; Lookingbill et al., 2010). However, wetlands are some of the most threatened ecosystems (Finlayson and Rea, 1999; Zedler and Kercher, 2005) due to human impacts, such as urbanisation and agricultural intensification.

Baixo Vouga Lagunar (BVL) is a coastal wetland in north-western Portugal that represents one of the most biologically-rich wetlands in Europe, supporting internationally important numbers of rare birds and plants (Brito et al., 2010). However, the small mammal communities and species distribution in the different habitats within this heterogeneous wetland landscape are virtually unknown.

In this study, we investigated the spatial and temporal dynamics of small mammal abundance and richness in a coastal wetland landscape in north-western Portugal. We evaluated the landscape characteristics of different habitats and the climatic conditions recorded during small mammal sampling in order to: i) determine which biotic and abiotic factors (namely landscape features and climate conditions) significantly affect small mammal abundance and species richness in a highly diverse landscape matrix; and ii) understand the influence of the landscape heterogeneity on small mammal abundance and richness.

We expected to find some differences in the small mammal abundance and richness over the sampled habitats, taking into account small mammal requirements and habitat characteristics, and also temporal fluctuations in small mammal abundance according to climate descriptors. Moreover, we expected to find a positive effect of the heterogeneous landscape on the small mammal fauna. Our results will enable a better integration of small mammal requirements into conservation and management of this heterogeneous wetland landscape.

3.3 MATERIALS AND METHODS

Study area

The study was conducted in an approximately 13,000 ha area of north-western Portugal (40º4''N, 8º33'-8º40'W), located in the Aveiro district, which included part of the Baixo Vouga Lagunar (BVL) (Figure 3.1). This area is a transitional region between Atlantic and Mediterranean climates (Costa et al., 1998). The BVL climate presents mild temperatures, with low temperature ranges, and high levels of humidity (Costa et al., 1998; Pinho et al., 2003). With mild winters and dry summers, the mean annual temperature recorded was 14.5 ºC, with a maximum temperature of 36.2 ºC registered in July 2012 and a minimum of -2.0 ºC in February 2012 (data from CUF® weather station, November 2011-October 2012). The annual cumulative rainfall recorded was 627.6 mm,

which occurred mainly between October and December, and in April (data from CESAMET, November 2011-October 2012).

As part of the Ria de Aveiro, BVL is a costal wetland area (Figure 3.1), which is of exceptional value due to its biomass production and biological diversity (Brito et al., 2010). There are two major landscape units: the agricultural mosaic composed of *Bocage* and farmlands (mainly maize and rice fields); and the wet system that comprises marshlands, rushes and reed beds (Brito et al., 2010).

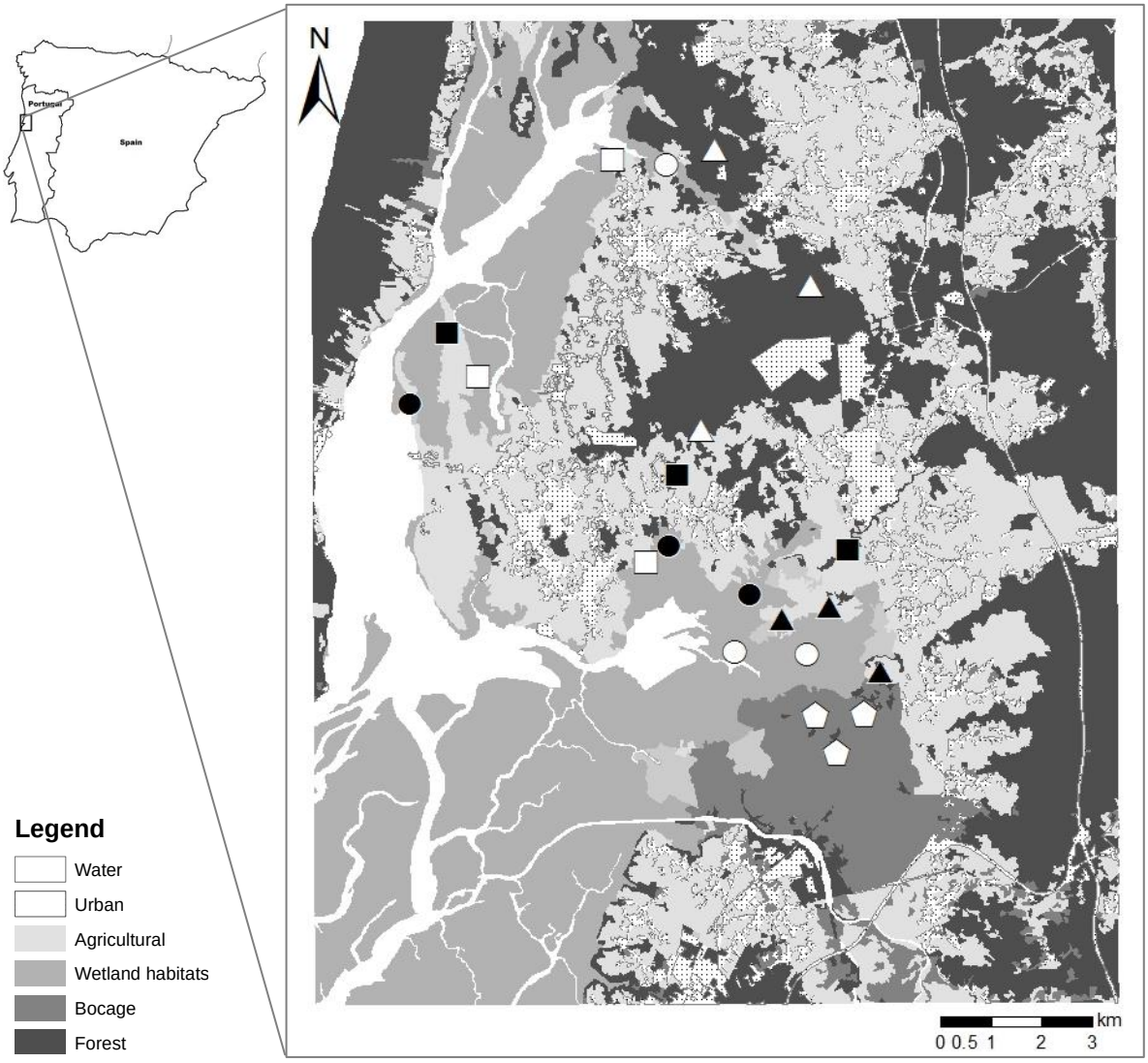

Figure 3.1 Location of the study area and the spatial distribution of sampling sites. Sampling sites are represented as follows: black circles are rushes; white circles as reed beds; black squares are maize fields, white squares are marshlands; black triangles are rice fields; white triangles are forest; white pentagons are *Bocage*

Landscape features

Sampling sites were selected in seven different habitats at BVL, characterised by different vegetation (Figure 3.1). Each sampled habitat – *Bocage*, maize fields, rice fields, forest, marshland, rushes and reed beds – has specific characteristics: i) *Bocage* is a mosaic landscape composed of typically small agricultural and pasture fields, separated by live fences of autochthonous trees (e.g. *Alnus glutinosa*, *Salix atrocinerea*, *Quercus robur*), shrubs and herb hedgerows (e.g. *Hedera* sp., *Rubus* sp.), which are connected by a dense network of narrow waterways; ii) maize fields are temporary crop fields of maize (*Zea mays*), which have the peculiarity of not exhibiting constant characteristics throughout the year, since it is a temporary culture; iii) rice fields are flooded fields dedicated to rice culture (*Oryza* sp.); iv) forests are woodland patches, mainly dominated by eucalyptus monocultures (*Eucalyptus* sp.); v) marshland is a low-lying wetland with halophyte vegetation, mainly dominated by *Spartina maritima*, *Salicornia ramosissima*, *Sarcocornia perennis* and *Halimione portucaloides*. It acts as a transition zone between land and saltwater, as well as occurring in rush and reed bed habitats; vi) rushes are a natural habitat comprised of large extensions of the common sea rush (*Juncus maritimus*); and vii) reed beds are a natural habitat where the influence of saline water is limited and are characterised by large extensions of *Phragmites australis*. These biotopes represent the different types of structural habitats that may be found in the semi-natural lowland environments of BVL.

Small mammal sampling

We designed a systematic population sampling protocol to provide quantitative estimates of small mammal species composition and abundance for the seven different habitats (*Bocage*, reed beds, maize fields, rushes, rice fields, marshland and forest) within the study area.

The sampling effort consisted of three replicates for each type of habitat, giving a total of 21 sampled sites (Figure 3.1). To minimise spatial auto-correlation, sampling sites were located at least 1000 m apart (Guisan and Zimmermann, 2000; Ascensão et al., 2012). Each site was sampled every two months, between November 2011 and October 2012, with one trap-line consisting of 30 Sherman^{TM} live traps placed 10 m apart. Capture-mark-recapture sessions were undertaken for five consecutive nights. Traps were baited with a mixture of hamster cereals, sardines and lacteal flour, and supplied with

cottonwood for nesting to reduce mortality from hypothermia during cold periods (Jones et al., 1996; Hodara and Busch, 2010). For each trapping session, every trap was checked daily in the early morning.

Captured rodents were identified based on external morphology (MacDonald and Barrett, 1993), sexed and weighed, and later released at the capture site. Shrews were identified based on external morphological and dental characteristics (MacDonald and Barrett, 1993) and weighed, but sex was not determined since sexual characters are difficult to distinguish in the field for this group (Gurnell and Flowerdew, 1994). Individuals of the genera *Microtus* and *Crocidura* were marked by hair clipping to allow identification in the following capture days. Wood mouse (*Apodemus sylvaticus*) and *Mus* sp. were marked with individual ear tags (Gurnell and Flowerdew, 1994).

Capture procedures and animal handling were in conformity with Portuguese Nature Conservation Institute directives (ICNF, Instituto da Conservação da Natureza e das Florestas) (ICNF permit no. 387/2011/CAPT and no. 96/2012/CAPT).

Data analysis

Small mammal diversity and abundance

Small mammal data are presented as species richness (defined as the number of different species identified in the three replicate samples for each type of habitat), diversity and abundance. Small mammal diversity was assessed by the modified Shannon-Wiener diversity index (D) (Jost, 2006), as follows:

$$D = \exp(-\sum_{i=1}^{s} pi \ln pi) = \exp(H')$$

Small mammal abundance was estimated using a relative abundance index (*Ii*), for each species, as follows:

$$Ii = Ni/(T * R - (C - r)) * 100$$

Where *Ni* is the number of animals of the species *i* captured, *T* the number of available traps, *R* the number of daily inspections of traps, *C* the number of captures of other species, and *r* the number of recaptures of species *i* (modified from Pounds, 1981).

Differences in the relative abundance index were assessed through Kruskal-Wallis tests (McDonald, 2008). All differences with $p<0.05$ were considered significant.

Landscape features assessment

The habitat types and landscape features were assessed according to buffer zones emanating from the trap line at each sampling site using ArcGIS® software. Buffers with different sizes of radius (8, 12, 28 and 110 m) were used for the genera *Crocidura*, *Mus*, *Microtus* and for *A. sylvaticus*, respectively. The buffers were set according to the largest home ranges mentioned in the literature for each species (*C. russula* – Wijnhoven et al., 2005; *M. spretus* – Gray et al., 1998; *M. agrestis* – Erlinge et al., 1990; *A. sylvaticus* – Rosalino et al., 2011). For species richness, buffers with a 110 m radius were used, based on the largest home range of *A. sylvaticus*.

The habitat patch types recorded in the buffer zones included *Bocage*, coastal water, fallow land, forest, maize fields, marshland, reed beds, rice fields, riparian gallery, rushes and urban. *Bocage* waterways were also recorded and, since they reflect an intrinsic characteristic of this habitat, hereafter they are considered as a *Bocage* variable. Measured landscape features included edge length, length of roads and waterways, and number of habitats. The edge length and number of habitats described the spatial heterogeneity at each sampling site (Scott et al., 2008).

Relating small mammal abundance and richness with landscape and climate descriptors

Landscape and climatic features were used as independent descriptors to model species abundance and richness. For each small mammal species, the relative abundance index was used as the response variable, whereas for species richness the response variable was the number of small mammal species. Generalized linear mixed models were used (GLMM's, Breslow and Clayton, 1993) with a logit link function, poisson distribution and Laplace approximation, using the R package 'lme4' (Bates et al., 2013). The analyses were performed by removing variables that explained the lowest proportion of the total variation until the most significant model was obtained (Guisan and Zimmermann, 2000).

Habitat (*Bocage* area, length of *Bocage* waterways, coastal water area, fallow land area, forest area, maize field area, marshland area, reed bed area, rice field area, riparian gallery area, rush area and urban area), landscape features (edge length, number of

habitats, length of roads and length of waterways), and climate descriptors (cumulative precipitation, mean temperature and maximum temperature) were used as fixed effects in models (Table 3.1). Replicate habitat sites were used as a random effect. Correlation between independent variables was checked with Spearman's Rank Correlation Coefficient for each small mammal species abundance and richness value using the 'Hmisc' R package (Harrell, 2013). Two variables were deemed strongly correlated when $rs > 0.7$. The variable with the highest correlation to the dependent variable was chosen or, under special circumstances, that with the greatest biological and ecological importance to the response variable. Models were ranked with the Akaike Information Criterion (AIC) according to their capacity to describe the data most parsimoniously (Burnham and Anderson, 2002). All statistical computation and plots were made in R software (R Core Team, 2013).

Table 3.1 Summary statistics of landscape and climatic variables used in the analysis. *A. sylvaticus* (Apo), genus *Mus* (Mus), genus *Microtus* (Mic), genus *Crocidura* (Cro), species richness (S)

Variables	Code	Description	Range	Apo	Mus	Mic	Cro	S
Habitat								
Bocage area	Boc	Proportion of *Bocage* area	0-10.37ha	✓	✓	✓		✓
Length of *Bocage* waterways	B.wat	Total length of fresh-waterways in *Bocage*	0-3848.23m				✓	
Coastal water area	Coast	Proportion of coastal water area	0-1.69ha	✓		✓		✓
Fallow land area	Fal	Proportion of fallow land area	0-0.93ha	✓		✓		✓
Forest area	For	Proportion of forest area	0-10.14ha	✓	✓	✓	✓	✓
Maize field area	Maize	Proportion of maize field area	0-9.64ha	✓	✓	✓	✓	✓
Marshland area	Marsh	Proportion of marshland area	0-8.42ha	✓	✓	✓	✓	✓
Reed bed area	Reed	Proportion of reed bed area	0-10.17ha	✓	✓	✓	✓	✓
Rice field area	Rice	Proportion of rice field area	0-8.89ha	✓	✓	✓	✓	✓
Riparian area	Rip	Proportion of riparian gallery area	0-0.50ha	✓				✓
Rush area	Rush	Proportion of rush area	0-9.50ha	✓	✓	✓	✓	✓
Urban area	Urb	Proportion of urban area	0-0.08ha	✓				✓
Landscape features								
Edge length	Edge	Length of edges between habitats	0-995.55m		✓			
Number of habitats	N.hab	Number of different habitats	1-5	✓		✓	✓	✓
Length of roads	Road	Total length of roads (dirt+asphalt)	405.79-2924.46m	✓	✓	✓	✓	✓
Length of waterways	Wat	Total length of waterways (fresh+salt)	0-911.23m	✓	✓	✓	✓	✓
Climate descriptors								
Mean temperature	Temp.m	Mean temperature during sample and previous day	7.70-19.74ºC	✓	✓	✓		✓
Maximum temperature	Temp.max	Maximum temperature during sample and previous day	14.63-36.20ºC				✓	
Cumulative precipitation	Prec	Cumulative precipitation during sample and previous day	0-48.80mm	✓	✓	✓	✓	✓

3.4 RESULTS

Small mammal diversity and abundance

A total effort of 18,665 trap-nights resulted in 1,961 captures of small mammals, including 566 recaptures (28.9% of total captures), of which 1,714 (87.4%) were rodents and 247 (12.6%) were shrews. Eight species were identified in the study area, comprising six rodent species – wood mouse (*Apodemus sylvaticus*), *Mus* sp., Lusitanian pine vole (*Microtus lusitanicus*), field vole (*Microtus agrestis*), southern water vole (*Arvicola sapidus*) and brown rat (*Rattus norvegicus*) – and two shrew species, *Crocidura* sp. and Iberian shrew (*Sorex granarius*) (Table 3.2). Three species, *A. sapidus*, *R. norvegicus* and *S. granarius*, were rarely recorded.

Table 3.2 Captures of small mammals in seven different habitats in BVL, including recaptures, from November 2011 to October 2012. Total captures per habitat (N), total captures per species and total trap nights (T), species richness (S) and modified Shannon-Wiener diversity index (D)

	Bocage	**Forest**	**Maize field**	**Marshland**	**Reed bed**	**Rice field**	**Rush**	**T**
Small mammal species								
Apodemus sylvaticus	120	312	52	33	99	224	93	**933**
Mus sp.	17	1	120	173	102	72	199	**684**
Microtus lusitanicus	9	0	0	2	58	11	0	**80**
Micotus agrestis	0	0	0	4	2	0	8	**14**
Crocidura sp.	24	13	26	51	55	18	59	**246**
Rattus norvegicus	0	0	0	1	0	0	0	**1**
Arvicola sapidus	0	0	0	1	1	0	0	**2**
Sorex granarius	0	0	0	0	1	0	0	**1**
N	**170**	**326**	**198**	**265**	**318**	**325**	**359**	**1961**
Trap nights	2675	2689	2636	2682	2662	2674	2647	18665
INDICES								
S	4	3	3	7	7	4	4	
D	2.64	1.32	2.48	2.88	4.18	2.40	2.96	

Apodemus sylvaticus, Crocidura sp. and *Mus* sp. were the only species that were present in all sampled habitats (Table 3.2). However, there was only one capture of *Mus* sp. in the forest (Table 3.2). Regarding the number of captures in each habitat, *A. sylvaticus* was the most captured species in *Bocage*, forest and rice fields. In maize fields, marshland and rush habitats, the genus *Mus* was the most abundant (Table 3.2). In general, voles were captured less frequently than rodents, so they were analysed as a genus (Table 3.2).

No recaptures were recorded between trap lines, so our sampling sites were assumed to be spatially independent. Regarding the relative abundances of the study species, we found no significant differences between habitat type replicates, except for the genus *Mus* in the maize field replicates (K=6.49, p=0.039) and the genus *Microtus* in the reed bed replicates (K=7.30, p=0.026) (see Table A.1 for Kruskal-Wallis test results).

Regarding small mammal richness, the lowest values were registered in forest and maize fields (n=3), and the highest values in reed beds and marshland (n=7) (Table 3.2). Small mammal diversity was higher in reed beds and lower in forest than in all the remaining habitats sampled (Table 3.2).

Relative abundances ranged from 0 to 51.18 individuals per habitat for *A. sylvaticus*; 0 to 22.35 individuals for the genus *Mus*; 0 to 9.4 individuals for the genus *Microtus*; and 0 to 7.48 individuals for the genus *Crocidura* (Figure 3.2). In general, *A. sylvaticus* was the species with highest values of relative abundance, only registering the lowest values in maize fields and marshland (Figure 3.2). For the genus *Mus,* the lowest relative abundances were registered in forest and *Bocage*, both woody habitats (Figure 3.2). Concerning the genus *Microtus*, it is worth noting that the highest values of relative abundance were recorded from reed beds and, for the genus *Crocidura,* in marshland, reed beds and rushes (Figure 3.2).

The abundance of *A. sylvaticus* was significantly higher in the forest than in the maize fields (K=10.90, p<0.001) and marshland (K=13.29, p<0.001) (Figure 3.2, Table A.2 in Appendix).

For genus *Mus* the abundance was significantly lower in the *Bocage* than in the maize fields (K=14.77, p<0.001), marshland (K=20.59, p<0.001), reed beds (K=15.19, p<0.001) and rushes (K=17.95, p<0.001). Also, in the forest, genus *Mus* abundance was significantly higher than in all other habitats (K_{maize}=22.67; K_{marsh}=28.64; K_{reeds}=25.57; K_{rice}=16.12, K_{rushes}=23.99, p<0.001), except *Bocage* (Figure 3.2, Table A.2 in Appendix).

The abundance of genus *Microtus* was significantly higher in the reed beds than in the forest and maize fields (both K=11.36, p<0.001) (Figure 3.2, Table A.2 in Appendix).

The abundance of the genus *Crocidura* was significantly higher in the rushes than in the *Bocage* (K=8.11 p<0.001). Also, in the marshland, it was higher than in all the forest (K=11.03, p<0.001) (Figure 3.2, Table A.2 in Appendix).

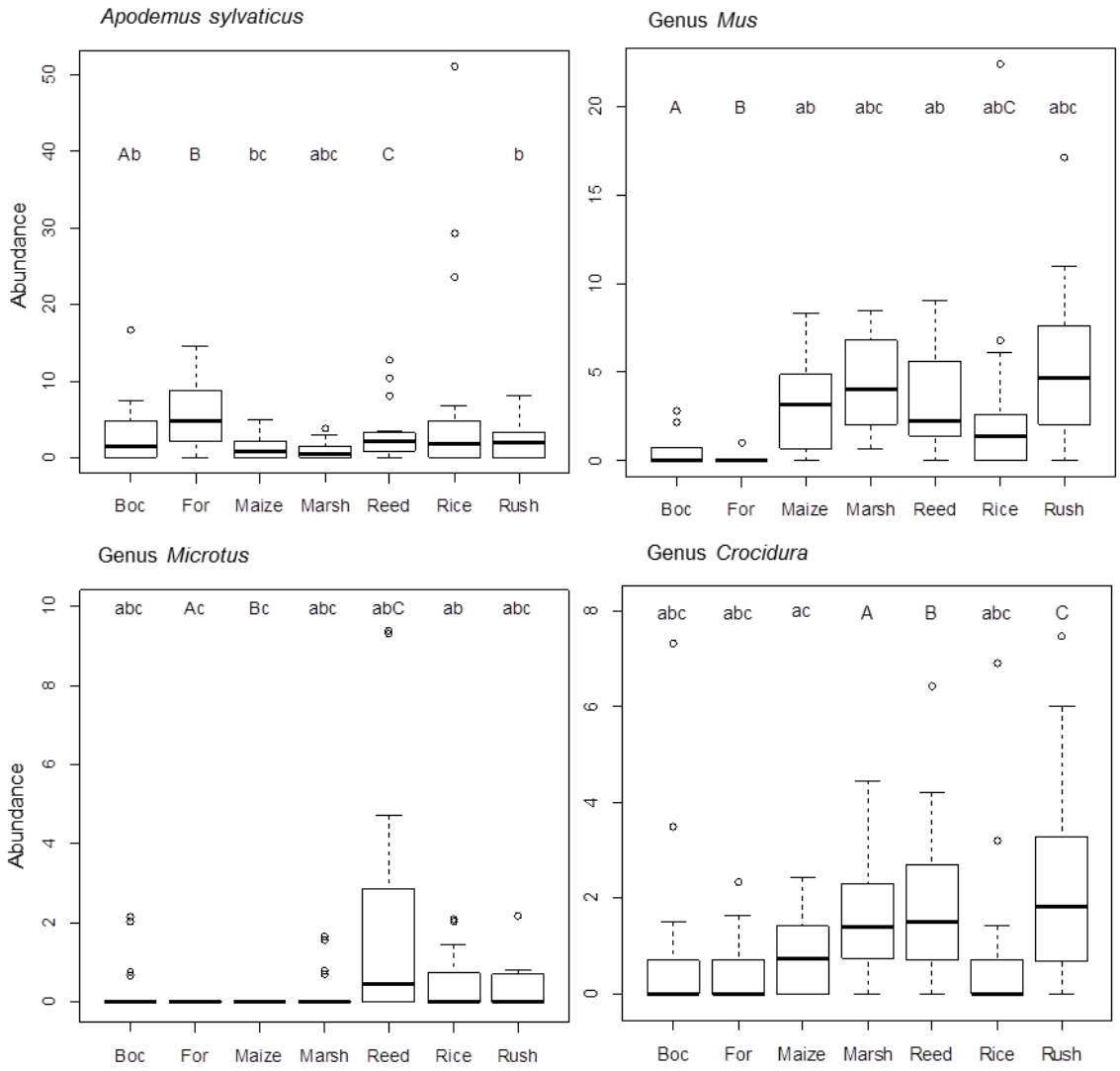

Figure 3.2 Boxplots of small mammal relative abundance for each sampled habitat type. *Boxplot upper and lower* limits represent the interquartile range (IQR), *thick line* is the median and ''*whiskers*'' are the ±1.5 x IQR. *Circles* are outliers. Sampling habitats consisted of agricultural areas with maize (Maize), marshland (Marsh), *Bocage* (Boc), forest (For), reed beds (Reed), rice fields (Rice) and rushes (Rush). Abundance refers to relative abundance index. Habitats marked with an *upper case letter* are significantly different ($p<0.05$) from all other habitats marked with *the lower case version of the same letter* (see Table A.2 in Appendix for Kruskal-Wallis test results)

Relating small mammal abundance and richness with landscape and climate descriptors

The best model (model A4, Table 3.3), which related the landscape and climate descriptors with the abundance of *A. sylvaticus* in BVL, included as significant predictors the rice field area, *Bocage* area, forest area, reed bed area and cumulative precipitation ($p<0.001$), all with a positive effect, while mean temperature ($p<0.001$) was negatively correlated (Table 3.4). This model accounted for 24% of the *w*AIC.

The most parsimonious model (model B5, Table 3.3) for describing variations in abundance of the genus *Mus* included *Bocage* area, forest area, rush area, marshland area, mean temperature, cumulative precipitation, length of roads and length of waterways as predictor variables (*w*AIC=0.29). The most significant predictors were *Bocage* area and forest area ($p<0.001$) with a negative effect, while cumulative precipitation ($p<0.001$) was positively correlated with *Mus* sp. abundance (Table 3.4). According to the ΔAIC ranking, the other models that had ΔAIC<2 (n=3), i.e. indicating relative similarity to the best model, all included *Bocage* area, forest area and cumulative precipitation. These three models accounted for 66% of the *w*AIC (Table 3.3).

For the genus *Microtus,* four models were obtained with ΔAIC<2, for which the best model (model C6 with a *w*AIC of 0.28, Table 3.3) included reed bed area as the most significant predictor ($p<0.01$), with a positive effect on *Microtus* spp. abundance (Table 3.4).

All models (ΔAIC<2) that best described *Crocidura* sp. abundance included forest area. Besides forest area (negative correlation) with greater significance ($p<0.001$), the best model (model D6, *w*AIC of 0.24, Table 3.3) also included rice field area, maize field area, number of habitats, length of *Bocage* waterways, maximum temperature and cumulative precipitation as predictor variables (Table 3.4).

For species richness the most parsimonious model (model E13, *w*AIC=0.22, Table 3.3) comprised *Bocage* area, reed bed area, forest area and mean temperature as predictor variables. The most important predictor of species richness was the forest area ($p<0.01$), with a negative effect (Table 3.4). According to the ΔAIC ranking, all models with the highest support (ΔAIC<2, n=5) included forest area as a predictor variable. These five models had a cumulative *w*AIC of 0.83 (Table 3.3).

In general, *Bocage* (Boc and B.wat) and forest area were the variables with the highest negative values correlating with small mammal abundance and richness. Reed bed area, rice field area, marshland area, rush area and cumulative precipitation were the variables with the most positive correlations to small mammal abundance (Table 3.5).

Table 3.3 Summary of the best models describing small mammal abundance and species richness at BVL. Variable codes as in Table 3.1. Akaike Information Criterion (AIC), measure of each model relative to the best model (ΔAIC) and Akaike weights (*w*AIC)

Models	Model code	Deviance	AIC	ΔAIC	*w*AIC
***Apodemus sylvaticus* abundance**					
Intercept only	A0	626.8	630.8	202.1	-
Rice+Boc+Reed+For+Rush+Maize+Marsh+Fal+Coast+Urb+N.hab+Prec+Temp.m	A4	398.7	428.7	0.00	0.24
Rice+Boc+Reed+For+Rush+Maize+Marsh+Fal+Coast+Urb+Prec+Temp.m	A5	401.4	429.4	0.70	0.17
Rice+Boc+Reed+For+Rush+Coast+Prec+Temp.m	A9	409.8	429.8	1.10	0.14
Rice+Boc+Reed+For+Rush+Maize+Marsh+Fal+Coast+Urb+N.hab+Prec+Temp.m+Rip	A3	398.1	430.1	1.40	0.12
Rice+Boc+Reed+For+Rush+Maize+Marsh+Coast+Prec+Temp.m	A7	406.9	430.9	2.20	0.08
***Mus* sp. abundance**					
Intercept only	B0	312.8	316.8	54.6	-
Boc+For+Rush+Marsh+Prec+Temp.m+Road+Wat	B5	242.2	262.2	0.00	0.29
Boc+For+Rush+Marsh+Prec+Temp.m+Road+Wat+Maize	B4	240.7	262.7	0.50	0.22
Boc+For+Rush+Marsh+Prec+Temp.m+Road+Wat+Maize+Rice	B3	239.5	263.5	1.30	0.15
Boc+For+Rush+Marsh+Prec+Temp.m+Wat	B6	246.4	264.4	2.20	0.10
***Microtus* spp. abundance**					
Intercept only	C0	138.7	142.7	33.10	-
Rice+Boc+Reed+Rush+Marsh+Coast+Prec+Temp.m+Road	C6	87.58	109.6	0.00	0.28
Rice+Boc+Reed+Rush+Marsh+Prec+Temp.m+Road	C7	89.9	109.9	0.30	0.24
Rice+Boc+Reed+Rush+Marsh+Coast+Prec+Temp.m+Road+Wat	C5	86.6	110.6	1.00	0.17
Rice+Boc+Reed+Rush+Marsh+Temp.m+Road	C8	93.25	111.2	1.60	0.13
Rice+Boc+Reed+Rush+Marsh+Coast+Prec+Temp.m+Road+Wat+N.hab	C4	85.93	111.9	2.30	0.09

Models	Model code	Deviance	AIC	ΔAIC	*w*AIC
***Crocidura* sp. abundance**					
Intercept only	D0	211.6	215.6	9.60	-
Rice+For+Maize+N.hab+B.wat+Prec+Temp.max	D6	188	206	0.00	0.24
Rice+For+Maize+B.wat+Prec+Temp.max	D7	190.5	206.5	0.50	0.19
Rice+For+Maize+N.hab+B.wat+Prec+Temp.max+Wat	D5	187.1	207.1	1.10	0.14
Rice+For+Maize+Boc.wat+Prec	D8	193.2	207.2	1.20	0.13
Rice+For+Maize+B.wat	D9	195.7	207.7	1.70	0.10
Rice+For+Maize+N.hab+B.wat+Prec+Temp.max+Wat+Rush	D4	186.2	208.2	2.20	0.08
Species richness					
Intercept only	E0	62.88	66.88	11.68	-
Boc+Reed+For+Temp.m	E13	43.2	55.2	0.00	0.22
Boc+Reed+For+Temp.m+Rip	E12	41.33	55.33	0.13	0.20
Boc+Reed+For+Temp.m+Rip+Rice	E11	39.84	55.84	0.64	0.16
Boc+Reed+For	E14	46.07	56.07	0.87	0.14
Boc+Reed+For+Temp.m+Rip+Rice+Fal	E10	38.48	56.48	1.28	0.11
Boc+Reed+For+Temp.m+Rip+Rice+Fal+Prec	E9	37.83	57.83	2.63	0.06

Table 3.4 Variables included in the models with the highest support (highest wAIC in Table 3.3) for small mammal abundance and species richness. Standard error (S.E.). Variable codes as in Table 3.1. Significance: '***' p<0.001; '**' p<0.01; '*' p<0.05; '.' p<0.1

Models/variables	Estimate	S.E.	Z	P
***A. sylvaticus* abundance**				
Intercept	-2.525920	1.344396	-1.879	0.060265 .
Rice	0.559416	0.130433	4.289	1.80e-0.5 ***
Boc	0.472947	0.128615	3.677	0.000236 ***
Reed	0.441551	0.126579	3.488	0.000486 ***
For	0.540150	0.130117	4.151	3.31e-05 ***
Rush	0.417892	0.134349	3.111	0.001868 **
Maize	0.323633	0.127132	2.546	0.010908 *
Marsh	0.456986	0.158670	2.880	0.003976 **
Fal	-0.702924	0.348717	-2.016	0.043826 *
Coast	0.549123	0.206829	2.655	0.007932 **
Urb	-26.941739	11.912535	-2.262	0.023720 *
N.hab	0.225414	0.135430	1.664	0.096026 .
Prec	0.030038	0.003133	9.586	<2e-16 ***
Temp.m	-0.126586	0.016061	-7.881	3.24e-15 ***
***Mus* sp. abundance**				
Intercept	-0.365946	0.394404	-0.928	0.35349
Boc	-2.241588	0.546336	-4.103	4.08e-05 ***
For	-4.189109	0.885335	-4.732	2.23e-0.6 ***
Rush	1.094813	0.375168	2.918	0.00352 **
Marsh	1.436567	0.465139	3.088	0.00201 **
Temp.m	0.034403	0.014893	2.310	0.02089 *
Prec	0.018997	0.003742	5.076	3.85e-07 ***
Road	0.002007	0.000952	2.109	0.03497 *
Wat	0.004696	0.001479	3.174	0.00150 **
***Microtus* spp. abundance**				
Intercept	-7.667e+00	3.381e+00	-2.267	0.023366 *
Rice	6.795e+00	2.220e+00	3.061	0.002208 **
Boc	6.304e+00	2.164e+00	2.913	0.003582 **
Reed	7.632e+00	2.180e+00	3.501	0.000464 ***
Rush	5.742e+00	2.117e+00	2.713	0.006675 **
Marsh	5.051e+00	2.069e+00	2.441	0.014640 *
Coast	-7.719e+04	5.088e+04	-1.517	0.129220
Temp.m	-8.117e-02	4.270e-02	-1.901	0.057316 .
Prec	1.775e-02	9.251e-03	1.918	0.055102 .
Road	-1.304e-02	4.208e-03	-3.099	0.001942 **

Models/variables	Estimate	S.E.	Z	P
***Crocidura* sp. abundance**				
Intercept	0.260095	0.454103	0.573	0.566803
Rice	-1.336296	0.710235	-1.881	0.059906 .
For	-2.605696	0.757016	-3.442	0.000577 ***
Maize	-1.626300	0.637860	-2.550	0.010784 *
N.hab	-0.262438	0.166554	-1.576	0.115096
Boc.wat	-0.004192	0.001632	-2.569	0.010190 *
Temp.max	0.025766	0.014969	1.721	0.085187 .
Prec	0.012617	0.006259	2.016	0.043807 *
Species richness				
Intercept	1.28217	0.23776	5.393	6.94e-08 ***
Boc	-0.04177	0.02070	-2.018	0.04360 *
Reed	0.03218	0.01785	1.802	0.07147 .
For	-0.06118	0.02374	-2.577	0.00996 **
Temp.m	-0.02593	0.01530	-1.695	0.09015 .

Table 3.5 Summary of the most significant variables (p<0.05) in the best model (ΔAIC=0) that explained small mammal abundance and richness. Significance: '***' p<0.001; '**' p<0.01; '*' p<0.05. (+) positive influence; (-) negative influence

	Boc	B.wat	Coast	Fal	For	Maize	Marsh	Reed	Rice	Rush	Urb	Road	Wat	Prec	Temp.m
Apodemus sylvaticus	*** (+)		** (+)	* (-)	*** (+)	* (+)	** (+)	*** (+)	*** (+)	** (+)	* (-)			*** (+)	*** (-)
***Mus* sp.**	*** (-)				*** (-)		** (+)			** (+)		* (+)	** (+)	*** (+)	* (+)
***Microtus* spp.**	** (+)						* (+)	*** (+)	** (+)	** (+)		** (-)			
***Crocidura* sp.**		* (-)			*** (-)	* (-)								* (+)	
Total (***)	2	0	0	0	3	0	0	2	1	0	0	0	0	2	1
Species richness	* (-)				*** (-)										

3.5 DISCUSSION

Small mammal abundance patterns

Small mammal species have different ecological requirements (e.g. Hansson, 1977; Palomo et al., 2009; Torre et al., 2002) and different abilities to use the resources available to them. Thus, small mammal abundance may vary at a given site, with a given set of resource and climatic parameters (Sainz-Elipe et al., 2012).

Apodemus sylvaticus, a typical seed-eater, was the best represented species in most of the sampled habitats in the BVL. Due to its wide distribution and generalist behaviour, this species occurs in a great variety of habitats and consumes a wide range of foods (Watts, 1968; Canova and Fasola, 1991; Khidas et al., 2002; Torre et al., 2002). This species is known as a dominant species of both natural and man-altered landscapes, and is not sensitive to habitat transformations (Watts, 1969; Michel et al., 2006; Sainz-Elipe et al., 2012). This high ecological plasticity was corroborated with our results in the BVL, since this species was captured both in the agricultural mosaic and in the wetland system typical of this area.

In general, the highest values of abundance for the genus *Mus* were registered in habitats with lower *A. sylvaticus* abundance (rs = -0.79). Our results agree with previous studies that have reported inter-specific competition between *A. sylvaticus* and *Mus spretus* in Mediterranean ecosystems (Boitani et al., 1985; Khidas et al., 2002). The spatial displacement of these two sympatric rodents could be a mechanism to reduce competition for resources, namely food, since they have very similar diets (Watts, 1968; Torre et al., 2002; Palomo et al., 2009).

Additionally, our results suggest that within the genus *Microtus* a similar pattern occurs in terms of inter-specific competition. Although *M. agrestis* and *M. lusitanicus* occur in sympatry, these two species do not appear to be syntopic within the BVL, which may reflect inter-specific competition in this environment. Santos et al. (2010) found a similar dynamic between *M. lusitanicus* and *M. duodecimcostatus* in a Mediterranean landscape (Portugal). However, the low capture rate of *genus Microtus* in our study area makes it difficult to draw robust conclusions in support of this hypothesis. This low capture success could be due to the methods used in the field, since these species have fossorial habits, using a subterranean gallery system (Aulagnier et al., 2009), and the traps were placed on the ground surface, which may have minimized captures. Further studies should investigate these relationships between sympatric small mammal species, clarifying the

role of habitat scale and interference competition in the distribution patterns found within the studied area.

Shrews, particularly the genus *Crocidura*, were less abundant than rodents in the BVL. This probably reflects the general view that shrews, being secondary consumers, occur in lower numbers in ecosystems than rodents, which are primary consumers (Canova, 1992). Nevertheless, the abundances of the genera *Crocidura* and *Mus* followed the same pattern throughout the sampled habitats, which is in concordance with the results of Sainz-Elipe et al. (2012), who reported very similar trapping success for *Crocidura russula* and *M. spretus* in unburned and burned habitats in a Mediterranean ecosystem (Spain). The similar population dynamics could be due to the fact that these species do not compete for the same food resources, since they have very distinct diets (insectivores vs. granivores, respectively) (Palomo et al., 2009; Brahmi et al., 2012).

Influence of landscape and climate features in small mammal abundance and richness

Small mammal abundance and richness reflects the habitat suitability for each species (Hansson, 1977, 1982, 1997; Loman, 2008). Our results revealed that forest and *Bocage* habitats did not favour the occurrence of several small mammal species. Forests were the habitat with the lowest small mammal diversity and that showed a significant negative effect on the small mammal fauna.

The forest in the BVL is mainly composed of eucalyptus monocultures and, as for any monoculture habitat, when compared to native forest, they tend to reveal lower faunal diversity (Saitoh and Nakatsu, 1997; Proença et al., 2010). In fact, in forested areas, vegetation homogeneity is inversely correlated to faunal diversity (Carey and Johnson, 1995). Forestry plantations managed for timber production are greatly simplified habitats with scarcer food resources than non-managed forests, and this may favour dominant species, impoverishing small mammal communities in terms of species diversity (Saitoh and Nakatsu, 1997; Matos, 2011). Hence, in having the highest values of abundance for the generalist species *A. sylvaticus* and lower values of small mammal diversity, together with the negative correlation of forest to the abundance of the genera *Mus*, *Crocidura* and species richness, our findings in forested sites are in agreement with previous studies (Saitoh and Nakatsu, 1997; Matos, 2011).

The *Bocage* is a mosaic landscape composed of typically small crop and pasture fields, separated by hedges and interspersed with a dense network of narrow waterways.

These characteristics make *Bocage* a very particular habitat. Many studies advocate that the hedgerow network is an important habitat for many species, including small mammals and carnivores (Michel et al., 2006; Sullivan et al., 2012; Pita et al., 2009). However, our results failed to support these findings for small mammals, since lower abundances of the genera *Mus* and *Crocidura*, and low small mammal richness were registered in the *Bocage*. These results could be due to a high predatory pressure by carnivores, which could be a regulating factor on small mammal populations (Erlinge et al., 1983; Bowers and Dooley, 1993; Hanski et al., 2001). However, further studies should investigate these predator-prey relationships, examining consistent multi-annual population oscillations of small mammals driven by predation in the rural mosaic of the BVL. Furthermore, the presence of cattle in this habitat could be another negative factor for the small mammal community, since grazing by cattle may alter the habitats by removing or modifying cover (Muck and Zeller, 2006).

In contrast, reed beds were the habitat with the highest diversity, favouring the occurrence of most small mammal species. The positive significant effect on small mammal fauna was evident in the abundance of *A. sylvaticus* and of the genus *Microtus*. This may be explained by the fact that reed seeds are abundant and easily available to rodents (Canova and Fasola, 1991). This result probably reflects the general view that food availability is one of the most important factors governing small mammal persistence, limiting individual survival and reproduction, as well as population dynamics (Hansson, 1979; Algelstam et al., 1987; Boutin, 1990; Gray et al., 1998; Ecke et al., 2001), and agrees with data from a previous study in an Estonian coastal wetland (Scott et al., 2008). The positive influence of rice fields on the abundance of *A. sylvaticus* and the genus *Microtus* may reflect the same assumptions, since rice grains could represent a food supply for these granivorous species (Singleton et al., 2005).

Also, rushes and marshlands, both wetland habitats, seemed to favour small mammal fauna, as reflected in their positive association with abundances of *A. sylvaticus* and the genera *Mus* and *Microtus*. This result is in agreement with several other studies that have reported the importance of wetland habitats for small mammals (e.g. Michelat and Giraudoux, 2006; Scott et al., 2008). Also, species of the genus *Microtus* are known to be inhabitants of wet and flooded habitats, such as reed beds, marshlands and rushes, and are able to swim during high tides, making them more adapted to surviving in these kinds of environments (Fisler, 1961; Balčiauskas et al., 2012).

In both natural and modified habitats, seasonality affects resource availability, leading to changes in the abundance of small mammal species (de Andreazzi et al., 2011;

Fischer et al., 2012). Abiotic factors, like temperature and rainfall, present temporal fluctuations, thus representing important factors in seasonality and having a direct influence on the availability of resources over different habitats (Ernest et al., 2000; de Andreazzi et al., 2011). Therefore, abiotic factors have a significant influence on the carrying capacity of the environment (Corominas, 1999) and, consequently, on the small mammal community. As expected, cumulative precipitation was an important predictive variable for the abundance of many small mammal species (*A. sylvaticus*, *Mus* sp. and *Crocidura* sp.), reflecting temporal fluctuations, which agrees with Torre et al. (1996). These authors reported a positive influence of rainfall on small mammal abundance in a Mediterranean habitat (Spain). This result may be due to the fact that rainfall improves the quality of lower-elevation habitats for small mammals, particularly rodents. Rain increases primary productivity (e.g. germination of herbaceous plants) (Mittelbach et al., 2001), leading to greater food availability, and to the development of vegetative cover, promoting the formation of tunnel systems that offer protection to small rodents from both predators and harsh weather (Corominas, 1999; Milstead et al., 2007). These are important factors for small mammal survival (Gray et al., 1998; Ecke et al., 2001). Moreover, the annual cycle of abundance of some species is correlated to climate descriptors (Ernest et al., 2000; Korpimäki et al., 2004). In particular, the annual abundance cycle of *A. sylvaticus* includes a spring decline and summer collapse in population density when temperatures are higher and rainfall is scarcer than in other seasons. In winter, when lower temperatures are felt and rainfall is more frequent and abundant, abundances of *A. sylvaticus* are higher (Watts, 1969; Montgomery, 1989; Moreno and Kufner, 1988).

However, it should be noted that climatic conditions influence small mammal abundance equally throughout the various habitats, reflecting temporal variations; the differences in peaks of abundance in distinct habitats throughout a patchy landscape are due to the particular characteristics of the small mammal species.

Besides the common factors influencing small mammal fauna, as discussed above, it is noteworthy that some species were influenced differently by the distinct habitats and, consequently, their distribution fluctuated throughout the patchy landscape. Certain habitats favoured some species, such as the genus *Microtus* by *Bocage* and *A. sylvaticus* by both forest and *Bocage*. In contrast, other species, such as those of the genera *Mus* and *Crocidura*, avoided forest and *Bocage* since their abundances were negatively correlated with these habitats.

Does landscape heterogeneity influence small mammal abundance and richness?

Landscape features may have impacts on small mammal populations and community dynamics (e.g. Fischer et al., 2012). Despite our expectation of finding a positive influence of landscape heterogeneity descriptors on small mammals (both in terms of abundance and richness), neither positive nor negative significant associations were found. In general, identical habitat patches in different locations within the landscape matrix (habitat replicates) were not significantly different in small mammal abundance. Furthermore, the representative variables of landscape heterogeneity (e.g. edge length and number of habitats) did not reveal a significant influence on small mammal abundance and richness. These results should be interpreted with caution since this study was performed at a fine-scale (species home range) and the effect of habitat heterogeneity on small mammals may differ in relation to the spatial scale of analysis (Tews et al., 2004; Fischer et al., 2011; Thornton et al., 2011). In fact, many studies that have found a positive influence of spatial heterogeneity on small mammal abundance and richness were performed at a broader spatial scale (e.g. Bowland and Perrin, 1993; Ecke et al., 2002; Scott et al., 2008). The fine-scale used in this study probably did not reflect the structural heterogeneity of the BVL landscape, so its effect on small mammal abundance and richness may have been underestimated.

The significant differences registered within the maize field and reed bed replicates for abundances of the genera *Mus* and *Microtus*, respectively, were an exception to this assertion and do not necessarily mean that it was due to an “effect of landscape surroundings”. Taking into account the habitat characteristics, these results may be due to the seasonality of human actions in these habitats, which was not temporally synchronized in the different patches sampled.

Overall, although at a fine-scale, landscape heterogeneity did not seem to influence small mammal abundance and richness, our results suggest that, at the landscape-scale, the mosaic of habitats found in the BVL favoured the small mammal fauna. In fact, several small mammal species were revealed to be differently influenced by the distinct habitats and, consequently, their distribution fluctuated throughout the patchy landscape. Our findings support the importance of wetlands for the small mammal community in the BVL landscape, emphasising reed beds as the habitat type with highest small mammal diversity among all of the habitats surveyed (Erlinge et al., 1983; Bowland and Perrin, 1993; Michelat and Giraudoux, 2006; Scott et al., 2008). Thus, wetlands are shown to be an important ecosystem element for small mammal populations and

communities, which are enmeshed in complex food webs involving resources and predators, the maintenance of which are vital for regional biodiversity. Factors associated with small mammal micro-habitat selection within these wetland systems can help identify the role of wetlands in the conservation of small mammal populations, as well as of their predators, in this Mediterranean heterogeneous landscape. However, it should be noted that conservation and management efforts in the BVL patchy landscape would often need to also consider the characteristics of the surrounding landscapes.

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3.7 APPENDIX

Table A.1 Results from the Kruskal-Wallis test performed on small mammal abundance between the three replicates of each habitat for each species (df=2). Significance: '***' p<0.001; '**' p<0.01; '*' p<0.05

	Bocage		**Forest**		**Maize field**		**Marshland**		**Reed bed**		**Rice field**		**Rush**	
	K	**p**	**K**	**p**	**K**	**p**	**K**	**p**	**K**	**p**	**K**	**p**	**K**	**p**
Apodemus sylvaticus	0.3702	0.831	0.4561	0.7961	0.08	0.9608	2.9002	0.2346	2.2426	0.3259	2.3571	0.3077	1.3256	0.5154
***Mus* sp.**	3.1658	0.2054	2	0.3679	6.4879	0.03901 *	1.3259	0.5153	5.8923	0.05254	0.1075	0.9477	5.5613	0.062
***Microtus* spp.**	1.0639	0.5875	NA[a]	NA[a]	NA[a]	NA[a]	4.3713	0.1124	7.3019	0.02597 *	4.3682	0.1126	1.1427	0.5648
***Crocidura* sp.**	4.2659	0.1185	2.3823	0.3039	4.5557	0.1025	3.1729	0.2047	4.7006	0.09534	0.7509	0.687	4.3637	0.1128

[a] Since all matrices were comprised of zeros, the Kruskal-Wallis test is not applicable

Table A.2 Results from the Kruskal-Wallis test performed on small mammal abundance between habitat types for each species (df=1). NA = not applicable. Significance: '***' p<0.001; '**' p<0.01; '*' p<0.05

	Bocage		**Forest**		**Maize field**		**Marshland**		**Reed bed**		**Rice field**	
	K	**p**	**K**	**p**	**K**	**p**	**K**	**P**	**K**	**p**	**K**	**p**
Apodemus sylvaticus												
Forest	4.314	0.0378 *	-	-								
Maize field	2.0332	0.1539	10.8954	0.000964 ***	-	-						
Marshland	3.9575	0.04666 *	13.2948	0.0002662 ***	0.2353	0.6276	-	-				
Reed bed	0.1581	0.6909	2.3099	0.1286	4.5569	0.03279 *	7.0753	0.007815 **	-	-		
Rice field	0.0165	0.8978	2.372	0.1235	1.8756	0.1708	3.3834	0.06586	0.0572	0.811	-	-
Rush	0.0432	0.8353	5.8087	0.01595 *	1.809	0.1786	3.6402	0.0564	0.7107	0.3992	0.103	0.7482
***Mus* sp.**												
Bocage	-	-										
Forest	3.164	0.07528	-	-								
Maize field	14.7711	0.0001214 ***	22.6727	1.921e-06 ***	-	-						
Marshland	20.5867	5.699e-06 ***	28.6367	8.731e-08 ***	1.4851	0.223	-	-				
Reed bed	15.1878	9.733e-05 ***	25.5678	4.271e-07 ***	0.1002	0.7515	2.1189	0.1455	-	-		
Rice field	6.8689	0.008771 **	16.1186	5.95e-05 ***	2.2278,	0.1355	7.4263	0.006428 **	1.7744	0.1828	-	-
Rush	17.9515	2.266e-05 ***	23.9891	9.688e-07 ***	1.8537	0.1734	0.0563	0.8124	3.37	0.06639	6.698	0.009652 **
***Microtus* spp.**												
Bocage	-	-										
Forest	4.3561	0.03688 *	-	-								
Maize field	4.3561	0.03688 *	NA[a]	NA[a]	-	-						
Marshland	0.0019	0.9653	4.3561	0.03688 *	4.3561	0.03688 *	-	-				
Reed bed	4.0946	0.04302 *	11.3551	0.0007524 ***	11.3551	0.0007524 ***	4.0946	0.04302 *	-	-		
Rice field	0.3858	0.5345	6.9252	0.008499 **	6.9252	0.008499 **	0.5201	0.4708	2.417	0.12	-	-
Rush	0.1402	0.7081	5.605	0.01791 *	5.605	0.01791 *	0.1108	0.7393	3.851	0.04972 *	0.1087	0.7416

	Bocage		Forest		Maize field		Marshland		Reed bed		Rice field	
	K	**p**	**K**	**p**	**K**	**p**	**K**	**P**	**K**	**p**	**K**	**p**
Crocidura sp												
Bocage	-	-										
Forest	0.0148	0.9032	-	-								
Maize field	1.146	0.2844	1.5731	0.2098	-	-						
Marshland	8.233	0.004113 **	11.0254	0.0008987 ***	4.4288	0.03534 *	-	-				
Reed bed	6.2259	0.01259 *	7.7738	0.005301 **	3.7086	0.05413	0.0023	0.9621	-	-		
Rice field	0.2727	0.6015	0.2191	0.6397	2.1193	0.1455	9.1962	0.002425 **	7.3763	0.006609 **	-	-
Rush	8.1102	0.004402 ***	7.6842	0.005571 **	4.6943	0.03026 *	0.2738	0.6008	0.1458	0.7026	7.9259	0.004873 **

[a] Since all matrices were comprised of zeros, the Kruskal-Wallis test is not applicable

Chapter 4

INFLUENCE OF HUMAN, PREY AVAILABILITY AND LANDSCAPE FEATURES ON CARNIVORE RICHNESS IN A HETEROGENEOUS COASTAL WETLAND, NW PORTUGAL

4. INFLUENCE OF HUMAN, PREY AVAILABILY AND LANDSCAPE FEATURES ON CARNIVORE RICHESS IN A HETEROGENEOUS COASTAL WETLAND, NW PORTUGAL

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4.1 ABSTRACT

Due to their large home ranges, mammalian carnivores are particularly susceptible to landscape features, such as habitat type and landscape complexity, as well as to resource availability and distribution, such as shelter and food supply. This study investigated the biotic and abiotic factors affecting carnivore assemblage in a heterogeneous wetland landscape. More specifically, we tested the influence of landscape features, human influence and prey availability on mammalian carnivore richness in Baixo Vouga Lagunar, north-western Portugal. Our results indicate that carnivore richness was mainly driven by landscape features, rather than by human influence and prey availability, or a combination of these factors. Among landscape features, length of freshwater lines seemed to favour the presence of carnivore fauna. On the other hand, exotic forest and edge length were found to negatively influence carnivore richness. Additionally, we found that prey availability did not affect carnivore richness, which might be a consequence of a spatially wide availability of small mammals throughout the landscape matrix. Overall, in

spite of the impoverished condition of the riparian habitats found in our study area, our findings support the importance of these areas to carnivore assemblage, by providingwater and shelter. Furthermore, since carnivore assemblage was negatively influenced by landscape heterogeneity and fragmentation, these linear elements may also act as connection links between patches within this landscape, thus reducing the negative biological effects of habitat loss and fragmentation. Hence, watercourses and riparian vegetation associated can be regarded as “keystone structures” to mammalian carnivores, and therefore, as important structures for their conservation within this heterogeneous wetland landscape.

Keywords Baixo Vouga Lagunar, ecological modelling, fragmentation, landscape heterogeneity, prey availability, riparian habitat

4.2 INTRODUCTION

Mediterranean ecosystems are typically composed by a mosaic of patches of distinct land cover classes. The inherent spatial heterogeneity of these environments is a result of natural disturbance regimes (e.g. Clavero et al., 2004; Boix et al., 2005), combined with long term anthropogenic influence (e.g. Caraveli, 2000; Pinto-Correia, 2000; Gomes et al., 2011; Salvati et al., 2012). The dynamics of these systems, induced by water flood regimes, land conversion, urban development and multi-use subsistence agriculture, has led to the destruction and fragmentation of many natural habitats (Saunders et al., 1991). Natural remnants are often immersed within these heterogeneous environments, which therefore encompass mosaics of optimal and sub-optimal habitats for wildlife (Santos et al., 2007; Rosalino et al., 2009; Van der Valk and Warner, 2009).

Due to their large home ranges (e.g. Cavallini and Lovari, 1994; Palomares and Delibes, 1988) mammalian carnivores are greatly affected by heterogeneous environments, quality of the matrix, connectivity and surrounding land-use types (Virgós, 2001; Constible et al., 2006; Pita et al., 2009; Rosalino et al., 2009). This may have important implications on the ecosystem structure and functioning, since small and medium carnivores often play fundamental roles in natural processes and in the maintenance of ecological equilibrium, namely by maintaining healthy populations of prey species, and avoiding overpopulation of undesirable species (Erlinge et al., 1983). Moreover, carnivores may contribute to the improvement of quality, conservation and

regeneration of the local flora, by controlling several herbivore populations, and acting as seed dispersers (Rosalino et al., 2010).

Many of the species inhabiting Mediterranean ecosystems are widespread and described as generalists species, able to adapt to various habitats (Aulagnier et al., 2009). Nevertheless, resource availability provided by a habitat is an essential factor for the development, functioning and maintenance of organisms, influencing population patterns (Rosalino et al., 2005; Mortelliti and Boitani, 2008; Šálek et al., 2013). In a heterogeneous landscape, differences in the productivity and structural complexity of vegetation between habitats, promote fluctuations in resource availability, which may influence the habitat suitability and, consequently, the distribution of mammalian carnivores (Virgós and Casanovas, 1999; Virgós, 2001; Virgós and García, 2002; Sarmento et al., 2010).

Carnivore coexistence in a certain habitat depends on resource availability, which should be sufficient to fulfil their basic needs (Šálek et al., 2013). In southern Europe, carnivores usually adopt a food and habitat complementation strategy to survive the resource limitations imposed by Mediterranean ecosystems (e.g. Lodé, 1994; Lucherini et al., 1995; Santos et al., 2007; Mortelliti and Boitani, 2008). Small mammals are the main prey-item in the diet of several small and medium size carnivores (e.g. Lodé, 1997; Virgós et al., 1999; Rosalino and Santos-Reis, 2002; Goldyn et al., 2003; Elmeros, 2006). Therefore, as key organisms in the trophic chain, variations in small mammal abundance and distribution can exert a significant influence on predator population fluctuations and distribution (Tapper, 1979; Karanth et al., 2004; Mortelliti and Boitani, 2008).

Regarding habitat and vegetation cover, the presence of abundant woody cover (i.e. shrub land patches, hedges, woodlots and riparian galleries) plays a critical role in promoting carnivore diversity and abundance within Mediterranean landscapes (Virgós and Casanovas, 1999; Mestre et al., 2007; Pita et al., 2009; Rosalino et al., 2009; Santos et al., 2011). Namely, riparian habitats are recognized as key elements for carnivore species in these landscapes, as they provide water, prey and shelter, and promote external temperature regulation (Rondinini et al., 2006; Matos et al., 2009; Pita et al., 2009; Rosalino et al., 2009; Pereira and Rodríguez, 2010; Santos et al., 2011). The riparian corridors are particular important for carnivores in highly deforested areas, since vegetation associated with streams may be the only remaining woodland providing shelter (Virgós, 2001). Additionally, these linear habitats act as corridors and reduce the negative biological effects of habitat loss and fragmentation, enhancing landscape connectivity (Červinka et al., 2013).

Understanding the distribution patterns and habitat selection of mammalian carnivores, which are species in the highest levels of food chains, is essential to build effective land management policies, where biodiversity conservation is a keystone. Therefore, the main aim of this study is to investigate the abiotic and biotic factors that influence carnivore richness in a heterogeneous coastal wetland landscape in north-western Portugal, Baixo Vouga Lagunar (BVL). Specifically, we aim to i) determine which type of factors (or combination) affect carnivore richness – landscape features, human influence and/or prey availability; and ii) identify keystone structures and/or limiting resources to the carnivore assemblage within the landscape matrix. The knowledge of the main factors affecting carnivore coexistence in a highly heterogeneous and fragmented landscape serves as an important precursor to management and conservation decisions regarding the heterogeneous landscape of Baixo Vouga Lagunar.

4.3 MATERIALS AND METHODS

Study area

The study area (Figure 4.1) is located in the Aveiro district (40º4'N, 8º33'-40'W) on the north-western Portuguese coast. It has an area of 8,400 ha which included part of a region known as Baixo Vouga Lagunar (BVL). To the south, the study area is limited by the Vouga River, and to the west by an estuarine coastal lagoon (Ria de Aveiro).

Concerning climate, the study area is a transition region between Atlantic and Mediterranean climates (Costa et al., 1998). The BVL climate is characterized by mild temperatures, low temperature ranges and high levels of humidity (Costa et al., 1998; Pinho et al., 2003). It is also characterized by a well-defined seasonal variation, presenting mild winters and dry summers. During the study perior, a mean annual temperature of 14.5 ºC was registered, with an amplitude between -2.0 ºC in February 2012 and 36.2 ºC in July 2012 (data from CUF® weather station, 2011-2012). The annual accumulative rainfall was 627.6 mm, with the highest values registered between October and December 2011, and in April 2012 (data from CESAMET, 2011-2012).

This region is characterized by a highly heterogeneous and complex landscape structure, dominated by agricultural land, mainly maize fields (Table 4.1). Maize fields are temporary cultures of maize (*Zea mays*), and therefore they do not exhibit constant characteristics throughout the whole year, due to land management. Besides maize fields,

there are also rice fields, although in much smaller extensions, which are flooded fields dedicated to the culture of *Oryza* sp.

One particularity of this complex wetland is the occurrence of various transition habitats between terrestrial ecosystems and saltwater, such as marshlands, rushes and reed beds (Table 4.1). Marshland is a low-lying wetland with halophyte vegetation, mainly dominated by *Spartina maritima*, *Salicornia ramosissima*, *Sarcocornia perennis* and *Halimione portucaloides*. Rush is a natural habitat with large extensions of the common sea rush (*Juncus maritimus*). Reed bed is a natural habitat characterized by large extensions of *Phragmites australis*, where the influence of saline water is limited.

Woody habitats are composed by *Bocage*, riparian gallery and forest (Table 4.1). *Bocage* is a mosaic landscape composed of agricultural and pasture fields, usually small-sized, separated by live fences of autochthonous trees (e.g. *Alnus glutinosa*, *Salix atrocinerea*, *Quercus robur*), shrub and herb hedgerows (e.g. *Hedera* spp., *Rubus* spp.), to which joins a dense network of narrow waterways. The riparian gallery is a linear habitat adjacent to inland aquatic systems, composed mainly by autochthonous woody vegetation (e.g. *Alnus glutinosa*, *Salix atrocinera*). The forest present in the study area is manly dominated by eucalyptus monocultures (*Eucalyptus* sp.).

Table 4.1 Habitat cover (area, percentage and number of patches) in the study area, BVL. Habitats are classified as “open habitat” and “woody habitat”

Habitat	Area (ha)	Area (%)	Patch number	Mean area patch	Open habitat	Woody habitat
Bocage	806.72	9.60	6	134.45		✓
Fallow land	281.60	3.35	16	17.60	✓	
Forest	1625.60	19.35	71	22.90		✓
Marshland	719.30	8.56	21	34.25	✓	
Reed bed	548.74	6.53	9	60.97	✓	
Riparian gallery	10.28	0.12	2	5.14		✓
Rush	715.87	8.52	16	44.74	✓	
Coastal water	351.54	4.19	1	351.54	✓	
Rivers	11.47	0.14	1	11.47	✓	
Maize field	2556.33	30.43	68	37.59	✓	
Rice field	119.30	1.42	2	59.65	✓	
Urban	653.35	7.78	117	5.58	✓	

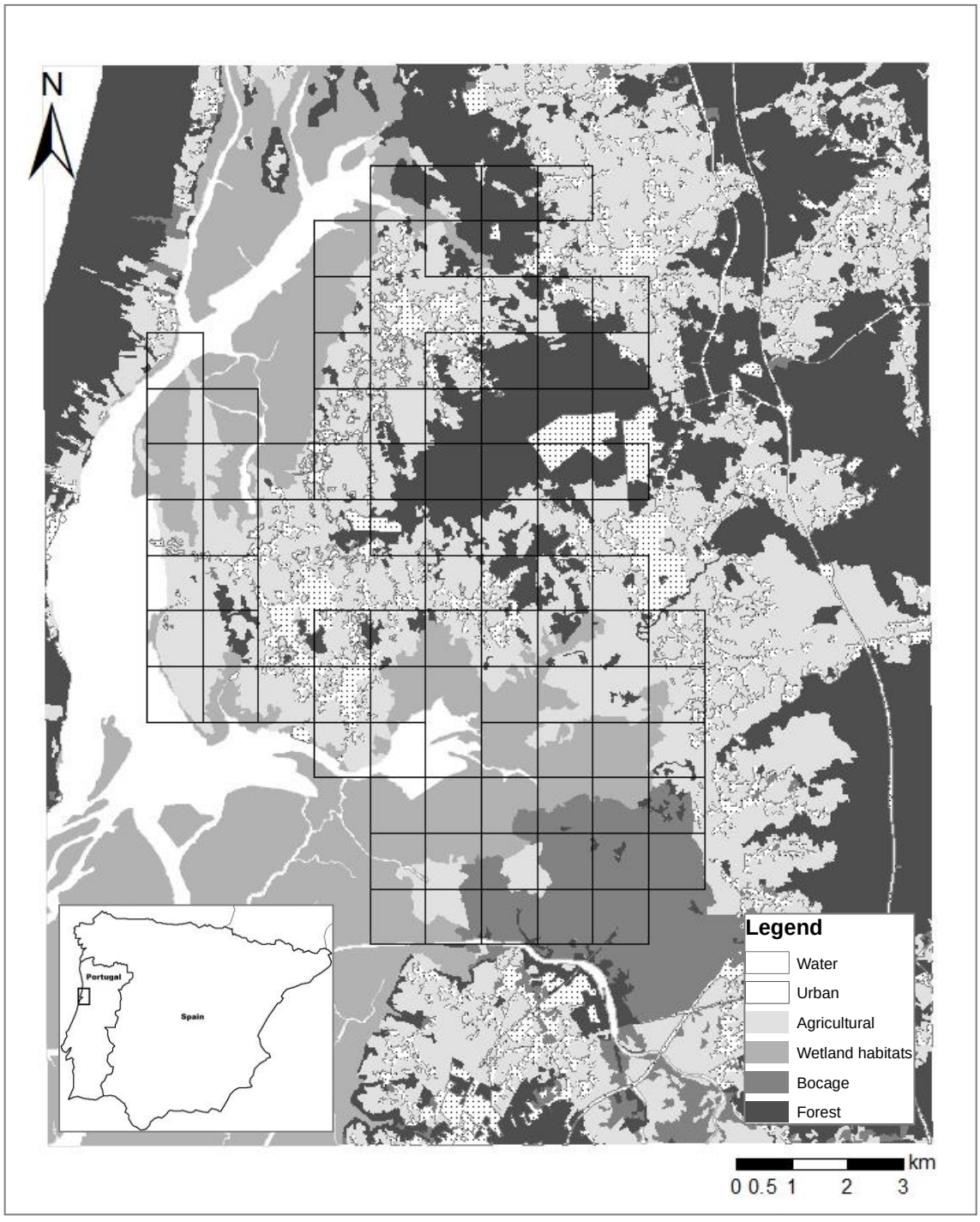

Figure 4.1 Location of the study area in the Iberian Peninsula and the sampled area with grid used

Carnivores and prey sampling

Due to the ecological differences among the diverse terrestrial mammal groups (carnivores and their prey – small mammals) that coexist in BVL, three different strategies were implemented at the sampling area: camera trapping and sign surveys for carnivores (Kendall et al., 1992; Wemmer et al., 1996; Wilson and Delahay, 2001) and a capture programme focused on small mammals (rodents and shrews) (Jones et al., 1996).

Carnivores sampling

The inventory of carnivore species and their distribution in the study area used a 1x1 km square as standard sampling unit size, based on the Universal Transverse Mercator (UTM) grid (Figure 4.1). The dimension of the sampling unit was chosen so that species home-ranges were taken into account, in order to balance between their behavioural ecology, the size of the area of interest and the aims of the study (Wemmer et al., 1996; Wilson and Delahay, 2001). To detect all carnivore species with ecological differences inhabiting in the study area, and because no single technique offered optimal efficiency to all target species and sites (Thorn et al., 2010), two non-invasive complementary methodologies were used: camera-trapping and sign surveys. These methodologies were performed under appropriate licenses from Instituto da Conservação da Natureza e Florestas (ICNF licence no. 382/2011/CAPT and no. 98/2012/CAPT).

Camera trapping sampling was carried out between January 2012 and June 2013. The 1x1km squares were randomly selected to prospection and camera trapping, in order to minimize spatial and temporal autocorrelation. This survey was conducted only once in each sub area of 1km^2, in a total of 72 sampling sites, during 15 consecutive days (15 trap nights), and using Bushnell® Trophy cameras. Cameras were placed approximately 20 cm aboveground, and vegetation within the field of view of the cameras was removed to avoid false shots. The sensitivity level of the sensor chosen was “normal” and each device was programmed to take three photographs at each contact, and set to a time interval of 1 s. All photos recorded the date, time, temperature and lunar phase. Camera trapping produces a low disturbance effect on the wildlife, improving carnivore detection probability at sites where sign is difficult to find or identify (Wemmer et al., 1996; Cutler and Swann, 1999).

Sign surveys, carried out between November 2011 and April 2012, consisted of one 500 m long diurnal transect for every 1 km^2 sampling unit. Each transect, sampled

once, was evenly distributed to cover all land uses and performed during 15 minutes by two persons (total effort of 30 minutes). All detected carnivore signs of presence and activity, such as footprints, scats and latrines were recorded. Signs were identified to species level based on colour, dimensions, position and presence of accompanying signs (Izquierdo and Báez, 2009; Sanz, 2010). The geographical locations of these signs were also recorded. Furthermore, presence of dogs and cattle was registered, obtained both by direct observation and sign detection, during prospection.

Additionally, despite not being a systematic methodology, between October 2009 and August 2013, every sporadic data from direct observations and sign detection of carnivores were registered, as well as their geographical location.

Sampling design for prey availability – small mammals

Prey availability (small mammal abundance and richness) was assessed with a systematic small mammal sampling in seven different habitats (*Bocage*, reed bed, maize field, rush, rice field, marshland and forest) at BVL. We sampled three replicates for each type of habitat, in a total of 21 sites, located at least 1000 m apart to minimize spatial autocorrelation (Ascensão et al., 2012).

Each site was sampled every two months, between November 2011 and October 2012, with one trap-line containing 30 Sherman^{TM} live traps with a 10 m interval. Traps were baited with a mixture of hamster cereals, sardine and lacteal flour, and supplied with cottonwood for thermal insulation (Keller and Schradin, 2008; Hodara and Busch, 2010). Capture-mark-recapture sessions were undertaken for five consecutive nights, and in each trapping session, every trap was checked daily on early morning.

Captured rodents and shrews were identified based on morphology and dental characteristics (MacDonald and Barrett, 1993), weighted, marked, and later released at capture site. Wood mouse (*Apodemus sylvaticus*) and *Mus* individuals were marked with individual metal ear tags (Gurnell and Flowerdew, 1994); Genus *Microtus* and *Crocidura* were marked with hair clippings for identification in the following capture days. Capture procedures and animal handling were performed under appropriated licenses from Instituto da Conservação da Natureza e das Florestas (ICNF license no. 387/2011/CAPT and no. 96/2012/CAPT).

Data analysis

Carnivore richness

Carnivore data obtained through each methodology was compiled into a single presence/absence dataset for each species, and for each sampling unit. Species richness (S) was defined as the total number of species present within each cell.

Prey diversity and abundance

Small mammal abundance, species richness (S) and diversity (D) were used to characterize small mammal fauna at each habitat. Species richness was defined as the total number of different species identified in each type of habitat. Small mammal diversity was assessed by the modified Shannon-Wiener diversity index (D) (Jost, 2006), as follows:

$$D = \exp(-\sum_{i=1}^{s} pi \ln pi) = \exp(H')$$

Small mammal abundance was estimated using a relative abundance index, for each species, as follows:

$$Ii = \frac{Ni}{T * R - (C - r)} * 100$$

Where Ni is the number of animals of the species i captured, T the number of available traps, R the number of daily inspections of traps, C the number of captures of other species, and r the number of recaptures of species i (modified from Pounds, 1981).

The prey availability was estimated for each 1 km^2 unit as the weighted abundance of small mammal fauna, attending to the abundance index of each small mammal species in different habitats sampled and to the proportion of each habitat in the cell. It was also calculated the weighted small mammal diversity and species richness for each cell, using the same method. Small mammal diversity and species richness may be important factors characterizing prey availability for the Mediterranean carnivores due to inherent abundance fluctuations in the cycle of some small mammal species (Pearson, 1966).

Landscape features assessment

Habitat type and landscape features were assessed from each sampled 1 km^2 square, using ArcGIS® software. The habitat types recorded in the cells included *Bocage*, coastal water, fallow land, forest, maize field, marshland, reed bed, rice field, riparian gallery, rush and urban (Table 4.1 and 4.2). Area occupied by each habitat within a cell was registered. The total length of *Bocage* waterways was also registered and, since they reflect an intrinsic characteristic of this habitat, hereafter it will be considered as a *Bocage* variable (Table 4.2). Measured landscape features included edge length, length of asphalt and dirt roads, length of freshwater lines (small streams and rivers, except *Bocage* waterways), length of saltwater lines, patch number and number of habitats (Table 4.1). The number of habitats described the spatial heterogeneity at each sampling site (Scott et al., 2008). Also edge length and patch number can be considered as fragmentation and heterogeneity measures of this particular patchy landscape, since the study area is characterized by many small patches of different habitats. Rice field, maize field, urban and length of asphalt and dirt road were considered as variables belonging to the human influence set (Table 4.2). The remaining habitat and landscape features variables were included in the landscape features set (Table 4.2).

Relating carnivore richness with landscape features, human influence and prey availability

The variables used as independent descriptors to model species richness were grouped into three sets of predictors: landscape features, human influence, and prey availability (Table 4.2). Carnivore species richness was used as the response variable. However, *Lutra lutra* was excluded from the species richness counts, due to the ecological differences from the remaining species. Due to their aquatic-obligate condition, leading to a recognized association with riparian habitats (Prenda et al., 2001), results would probably be biased towards these environments (Matos et al., 2009; Santos et al., 2011). For the analysis were performed generalized linear models (GLM's) with a logit link function, Poisson distribution and Laplace approximation, using the R software.

Ten landscape features (*Bocage* area, fallow land area, forest area, marshland area, reed bed area, rush area, number of habitats, edge length, length of freshwater lines and length of saltwater lines), six anthropic (maize field area, rice field area, length of asphalt roads, length of dirt roads, presence of cattle and presence of dogs), and two prey

availability variables (small mammals abundance and diversity) were used as independent descriptors in model construction (Table 4.2).

We used Spearman's Rank Coefficient to evaluate correlations between independent variables, using the 'Hmisc' R package (Harrell, 2013). Two variables were considered strongly correlated when $rs > 0.7$, and we used only the one with higher correlation with the dependent variable or, in a special circumstance, the most biologically meaningful variable. We used the Akaike Information Criterion (AIC) to rank the models according to their capacity to describe the data parsimoniously (Burnham and Anderson, 2002). All statistical computation was made in R software (R Core Team, 2013).

Table 4.2 Description of the variables used in each data analysis. Landscape features (L), Human influence (H), Prey availability (P)

Variables	Code	Description	Range	L	H	P	L*H	L*P	H*P	L*H*P
Landscape features										
Bocage area	Boc	Proportion of *Bocage* area	0-97.25ha	✓			✓	✓		✓
Fallow land area	Fal	Proportion of fallow land area	0-41.38ha	✓			✓	✓		✓
Forest area	For	Proportion of forest area	0-98.88ha	✓			✓			
Marshland area	Marsh	Proportion of marshland area	0-76.70ha	✓			✓	✓		✓
Reed bed area	Reed	Proportion of reed bed area	0-83.47ha	✓			✓	✓		✓
Rush area	Rush	Proportion of rush area	0-74.28ha	✓			✓			
Number of Habitats	N.hab	Number of different habitats	2-8	✓			✓	✓		✓
Edge length	Edge	Length of edge	300.96-14234.20m	✓			✓	✓		✓
Length of saltwater lines	S.wat	Length of saltwater lines	0-5148.53m	✓			✓			
Length of freshwater lines	F.wat	Length of freshwater lines	0-2102.45m	✓			✓	✓		✓
Human influence										
Maize field area	Maize	Proportion of maize field area	0-81.13ha		✓		✓		✓	✓
Rice field area	Rice	Proportion of rice field area	0-48.88ha		✓		✓		✓	✓
Cattle	Cat	Presence of cattle	Pres/Aus		✓		✓		✓	✓
Dog	Dog	Presence of dog	Pres/Aus		✓		✓		✓	✓
Length of asphalt road	R.asph	Length of asphalt roads	0-7494.89m		✓		✓		✓	✓
Length of dirt road	R.dirt	Length of dirt roads	0-8309.13m		✓		✓		✓	✓
Prey availability										
Small mammal abundance	A.smm	Relative abundance of small mammals	0.06-5.03			✓		✓	✓	✓
Small mammal diversity	D.smm	Diversity of small mammals	1.32-4.00			✓		✓	✓	✓

4.4 RESULTS

Carnivore richness

We recorded in the study area six different carnivore species, belonging to three families: Canidae (red fox, *Vulpes vulpes*), Mustelidae (european polecat, *Mustela putorius*; weasel, *Mustela nivalis*; european badger, *Meles meles*; eurasian otter, *Lutra lutra*) and Viverridae (common genet, *Genetta genetta*) (Table 4.3).

Table 4.3 Summary carnivore species data detected during the field work, between 2009 e 2013, outcome from different methodologies. CT camera trapping; SS sign survey; SR sporadic records; TD total data resulted from combined methodologies

	Cells number				% presence
	CT	**SS**	**SR**	**TD**	**(TD)**
Carnivore species					
Vulpes vulpes	26	49	15	66	78.57
Genetta genetta	20	11	11	29	34.52
Mustela putorius	1	16	7	23	27.38
Mustela nivalis	1	6	8	14	16.67
Meles meles	9	2	2	11	13.10
Lutra lutra	3	9	11	17	20.24
Total cells survey	72	84	24	84	

Vulpes vulpes was the most widely distributed species, being present in 78,57% of all sampled units (1x1km squares) (Table 4.3). *Meles meles* had the most restricted distribution, being present only in 13,10% of the sampled area, followed by *Mustela nivalis*, occurring only in 16.67% of the study area (Table 4.3).

Prey availability

A total of 18,665 trap-nights effort resulted in a total of 1,961 captures, including 566 recaptures (28,9% of total captures), from which 1714 (87,4%) were rodents and 247 (12,6%) were shrews. Eight species were identified in the study area, including six rodent species – wood mouse (*Apodemus sylvaticus*) (n=909), *Mus* sp. (n=679), lusitanian pine vole (*Microtus lusitanicus*) (n=75), field vole (*Microtus agrestis*) (n=14), southern water

vole (*Arvicola sapidus*) (n=2) and brown rat (*Rattus norvegicus*) (n=1) – and two shrew species – *Crocidura* sp. (n=242) and iberian shrew (*Sorex granarius*) (n=1).

Apodemus sylvaticus presented higher abundances in the *Bocage*, forest, reed bed and rice field habitats than all the other species (Table 4.4). In the remaining habitats (maize field, marshland and rush), *Mus* sp. was the species with higher abundances. In general, rice field was the habitat with the highest small mammal abundance, and *Bocage* with the lowest (Table 4.4).

Table 4.4 Mean abundances of small mammals, diversity and species richness in seven different habitats, in BVL, 2011-2012. Sum of mean abundances per habitat (Σ), Species richness (S) and modified Shannon-Wiener diversity index (D)

	Bocage	**Forest**	**Maize field**	**Marshland**	**Reed bed**	**Rice field**	**Rush**
Small mammal species							
Apodemus sylvaticus	3.17	5.84	1.18	0.86	3.15	7.38	2.19
Mus sp.	0.48	0.06	3.33	4.42	3.03	2.85	5.29
Microtus sp.	0.31	0.00	0.00	0.26	1.97	0.43	0.29
Crocidura sp.	0.92	0.51	0.86	1.66	1.83	0.80	2.30
Σ	4.88	6.41	5.36	7.20	9.98	11.46	10.07
Indices							
D	2.64	1.32	2.48	2.88	4.18	2.40	2.96
S	4.00	3.00	3.00	7.00	7.00	4.00	4.00

Relating carnivore richness with landscape structure, human influence and prey availability

According to AIC ranking, the set of factors that better explained carnivore richness was landscape features. For this group of variables, we obtained two models with ΔAIC<2, where the best model (model A8, Table 4.5) included forest area, edge and length of freshwater lines as response descriptors (wAIC=0.12), with identical significance ($p<0.05$). The forest area and edge were negatively correlated to carnivore richness, opposite to the positive correlation found for the length of freshwater lines (Table 4.6).

Table 4.5 Summary of the best models describing carnivore richness at BVL. Variable codes as in Table 4.2. Akaike Information Criterion (AIC), measure of each model relative to the best mod (ΔAIC) and Akaike weights (wAIC)

Models	Model code	AIC	ΔAIC	*w*AIC
Landscape features				
Intercept only	A0	253.83	5.46	-
For+Edge+F.wat	A8	248.37	0.00	0.12
For+Edge+F.wat+Boc	A7	249.88	1.51	0.06
For+Edge+F.wat+Boc+N.hab	A6	251.06	2.69	0.03
Human influence				
Intercept only	B0	253.83	5.46	-
Asph.r	B6	251.56	3.19	0.03
Prey availability				
Intercept only	C0	253.83	5.46	-
D.smm	C2	251.03	2.66	0.03
Landscape features+human influence				
Intercept only	D0	253.83	5.46	-
For+F.wat+Asph.r	D14	250.12	1.75	0.05
For+F.wat+Asph.r+Edge	D13	250.36	1.99	0.05
F.wat+Asph.r	D15	251.2	2.83	0.03
Landscape features+Prey availability				
Intercept only	E0	253.83	5.46	-
Boc+F.wat+D.smm	E7	249.17	0.8	0.08
Boc+F.wat+D.smm+Edge	E6	249.8	1.43	0.06
F.wat+D.smm	E8	249.87	1.5	0.06
Boc+F.wat+D.smm+Edge+N.hab	E5	251.1	2.73	0.03
Human influence+Prey availability				
Intercept only	F0	253.83	5.46	-
Rice+D.smm	F7	251.7	3.33	0.02
Landscape features+Human influence+Prey availability				
Intercept only	G0	253.83	5.46	-
F.wat+Asph.r+D.smm	G13	250.5	2.13	0.04
F.wat+Asph.r+D.smm+Boc	G12	250.72	2.35	0.04

Table 4.6 Variables included in the models with the highest support (highest wAIC in Table 4.5) for carnivore richness. Standard error (S.E.). Variable codes as in Table 4.2. Significance: '***' p<0.001; '**' p<0.01; '*' p<0.05; '.' p<0.1

Models/variables	Estimate	S.E.	Z	P
Landscape features				
Intercept	8.956e-01	1.832e-01	4.887	1.02e-06 ***
For	-7.865e-03	3.353e-03	-2.346	0.0190 *
Edge	-6.697e-05	3.043e-05	-2.200	0.0278 *
F.wat	3.947e-04	1.589e-04	2.484	0.0130 *

4.5 DISCUSSION

Carnivore assemblage

Mediterranean habitats of the Iberian Peninsula harbour a diverse carnivore assemblage (e.g. Gomes, 1998; Mestre et al., 2007; Matos et al., 2009; Pita et al., 2009). We recorded six different species (*Vulpes vulpes*, *Mustela putorius*, *Mustela nivalis*, *Meles meles*, *Lutra lutra*, *Genetta genetta*) within the heterogeneous wetland landscape of BVL, north-western Portugal. Previous studies with carnivores in Mediterranean ecosystems, specifically in southern Portugal, reported similar species richness (Matos et al., 2009; Santos et al., 2011).

Despite this richness, the carnivore assemblage in the study area was largely dominated by only one widespread and abundant generalist predator, *Vulpes vulpes*, which is a native species. This species occurs in the majority of the study area (78.6%). Since BVL is a highly heterogeneous landscape, this concurs with the known generalist character of this species in terms of habitat (Cavallini and Lovari, 1991; Cavallini and Lovari, 1994; Lucherini et al. 1995). In fact, this species is widely distributed not only in the study area, but all over the Portuguese territory (Matos et al., 2009; Pita et al., 2009; Sarmento et al., 2011; Pereira et al., 2012).

Most of the remaining carnivore species showed restricted distributions in the study area, particularly *Meles meles* and *Mustela nivalis*, which were only detected in 13.10% and 16.67% of the sampled area, respectively. These findings may suggest that both these species have restricted habitat requirements, as already reported by Rosalino et al. (2005) and Zub et al. (2008), for *Meles meles* and *Mustela nivalis*, respectively.

Furthermore, *Mustela nivalis* have small home ranges and small-sized presence signs (King, 1975; Izquierdo and Báez, 2009; Sanz, 2010) which can challenge their detection in the field, even when using complementary field methods.

Lutra lutra also was detected in a small percentage of the study area (20,24%). However, this result may not reflect the real distribution of this semi-aquatic mustelid throughout the landscape matrix. This species have very particular ecological requirements, with an aquatic-obligate condition, and therefore a recognized riparian habitat association (Prenda et al., 2001), and the adopted surveying methods were not focused on these environments.

Carnivore responses to human, prey availabily and landscape features

Due to their large home ranges, mammalian carnivores are particularly susceptible to the spatial features, such as habitat type and landscape complexity, as well as to resource availability, such as shelter and food supply (Lodé, 1994; Mangas et al., 2008; Mortelliti and Boitani, 2008; Svobodová et al., 2011; Thornton et al., 2011). We found that carnivore richness was mainly driven by landscape features, rather than by human influence and prey availability, or a combination of these. Surprisingly, according to our results and the analysed variables, human influence and prey availability seemed not to be constraint factors for carnivore species in the BVL. However, it is noteworthy that our most parsimoniously model did not explained a great proportion of the variability of the carnivore richness. This can be due to the lack of relevant variables to the carnivore species occurrence, namely human influence descriptors such as direct persecution (e.g. illegal hunting, killing or capturing of wild animals). In fact, human influence occurs in various forms in the study area, one of them being poaching, however their evaluation and quantification is not easy.

Among the significant landscape features, our results showed a positive influence of freshwater lines on carnivore richness, which agree with several previous studies in Mediterranean landscapes (Virgós and Casanovas, 1999; Mestre et al., 2007; Pita et al., 2009; Santos et al., 2011). However, several ecological factors may be behind this result, as investigated by Santos et al. (2011) in a Mediterranean riparian ecosystem. One of those factors is water availability, since these structures provide freshwater to the fauna inhabiting these areas, including carnivores (Western, 1975; Santos et al., 2011). In fact, within the study area, freshwater may be one of the scarcer resources for the carnivore assemblage, since the majority of water channels are salty or brackish. Hence, in this

perspective, our results reinforce riparian areas as attractive places to carnivores, where they can survive water shortages, as reported by Santos et al. (2011).

Moreover, these landscape structures are generally associated to woody vegetation, namely riparian gallery. Despite riparian gallery appear to be a very scarce habitat; registered only in 0.12% of study area (Table 4.1), these values refer only to riparian corridors with considerable areas, which are visible in satellite imagery using large scales. Hence, riparian vegetation along small streams may have been neglected, being the actual riparian area larger than the one registered. Thus, the positive influence of woody habitats on carnivore diversity, already described for instance, by Pita et al. (2009) and Rosalino et al. (2009), is likely to be another of the possible explanations for the observed carnivore positive response to the freshwater lines. Several authors reported that riparian vegetation can act as safe harbourages for carnivores (Rondinini et al., 2006; Mestre et al., 2007; Matos et al., 2009; Pita et al., 2009; Pereira and Rodríguez, 2010; Santos et al., 2011). Virgós (2001) emphasized the importance of riparian areas for carnivore species in matrices of intensively-cultivated and highly-deforested areas, since the vegetation associated with streams may be the only remaining woodland. Hence, we hypothesize that the role of freshwater lines and the associated vegetation (i.e. refuge habitats) for carnivores in the BVL landscape depends upon the surrounding matrix composition. Since the heterogeneous wetland landscape of BVL is composed mainly by open environments, the shelter provided by riparian areas remnants may be a scarce resource to carnivore assemblage. Similar results were found by Rosalino et al. (2009) for mammalian diversity in a Mediterranean landscape. More generally, these findings agree with the idea that, at a given site, the scarce resource is the most determinant factor in animal distribution (e.g. Rosalino et al., 2005).

Besides providing water and shelter, riparian galleries may also act as connection links between patches within the landscape matrix, reducing the negative biological effects of habitat loss and fragmentation (Šálek et al., 2009; Červinka et al., 2013). This increase in landscape connectivity is another possible explanation to the positive influence of freshwater lines on carnivore richness. Some carnivore species are known to use linear structures, such as riparian galleries, during their daily and dispersal movements (Šálek et al., 2009), which function as ecological corridors (Červinka et al., 2013). Our results agree with Matos et al. (2009) that reported significantly higher species richness in corridors than in the landscape matrix, in a Mediterranean ecosystem.

Several studies in heterogeneous landscapes reported that animal species diversity is closely linked to “keystone structures” (Lima and Gascon, 1999; Pita et al.,

2009; Rosalino et al., 2009; Pereira and Rodríguez, 2010). These structures were defined as a "distinct spatial structure providing resources, shelter or 'goods and services' crucial for other species" (Tews et al. 2004). Despite of the impoverished condition of the riparian habitat found in our study area, our results suggest that watercourses and consequently, riparian areas, are qualified to be a keystone structure to mammalian carnivores in this heterogeneous wetland region.

On the other hand, our results revealed that carnivore richness was negatively influenced by forest cover. This can be due to the fact that forest patches in the study area are mainly plantations dominated by exotic tree species such as eucalyptus (*Eucalyptus* sp.). Monocultural forestry plantations often harbour a reduced animal diversity, when compared to native forests (Marsden et al., 2001; Proença et al., 2010), and are frequently avoided by carnivores (Sarmento et al., 2010; Matos, 2011). Forestry plantations, namely the ones managed for timber production, are greatly simplified habitats for animals. Therefore, they may not provide adequate conditions for fauna subsistence or establishment, such as understory vegetation, nesting sites or feeding resources (Marsden et al., 2001; Zahn et al., 2009).

Contrasting, heterogeneous landscapes may be favourable environments for generalist mammalian predators (Crooks, 2002; Mestre et al., 2007; Pita et al., 2009; Rosalino et al., 2009; Pereira et al., 2012). Since they provide more niches and different ways of exploiting the environmental resources (Bazzaz, 1975; Andén, 1994), heterogeneous landscapes may support a more diverse carnivore assemblage (habitat heterogeneity hypothesis – MacArthur and MacArthur, 1961). On the other hand, in fragmented landscapes carnivores tend to exhibit a specific habitat preference for edge structures, as found by Šálek et al. (2010) and Svobodová et al. (2011) in Czech Republic. However, in our study carnivore richness was negatively influenced by edge length. This landscape feature may be considered as a fragmentation and heterogeneity measure in the landscape matrix of the BVL, due to its particular characteristics (landscape mosaic dominated by small patches of diverse habitats). In fact, generally an increase in edge length in the BVL landscape is associated to an increase in the patch number (fragmentation) and, certainly, to an increase in the number of different habitats (heterogeneity). Hence, our results suggest that the landscape heterogeneity, and the associated fragmentation, did not enhance carnivore community. Previous research also showed that habitat heterogeneity and fragmentation may decrease carnivore diversity (Crooks, 2002). This negative effect may be a consequence of disruption of key biological processes such as dispersal and resource acquisition caused by the fragmentation

inherent to heterogeneity (Saunders et al., 1991). The BVL landscape is characterized by spatial discontinuity, presenting small habitat patches immersed in a human-modified matrix. Dominated by open habitats, in BVL there are few available corridors and linear structures that enhance landscape connectivity. Therefore, these features may restrict the movement of organisms and disrupt ecological processes across the landscape, impoverishing carnivore assemblage. Once more, these findings reinforced the importance of linear structures as riparian gallery in the landscape matrix of BVL by enhancing connectivity, as mentioned above.

Why prey availability did not seem influence carnivore richness?

Prey availability is often considered one of the key factors in carnivore distribution and habitat use (Rosalino et al., 2005; Červinka et al., 2013). Usually, in Mediterranean ecosystems carnivores adopt a food and habitat complementary strategy to overcome resource limitations (Lodé, 1994; Lucherini et al., 1995; Mortelliti and Boitani, 2008). Our results fail to support these findings, suggesting that prey availability did not have a significant effect on determining carnivore assemblage. Other authors also have found controversial results about the significance of prey availability to the carnivore community (Rosalino et al., 2005; Šálek et al., 2010). According to resource dispersion hypothesis (RDH), if resources are heterogeneous in space or time, group living might be less costly than was previously thought, regardless of whether individuals gain direct benefits from group membership (Macdonald, 1983). Hence, large resource patchiness causes territories of multiple animals to overlap, promoting spatial coexistence of carnivores in determined areas with higher resource availability (Červinka et al., 2013; Šálek et al., 2013). In BVL, prey availability appeared to be spatially homogeneous, since we did not find considerable differences among habitats regarding their small mammal abundance values. Hence, we hypothesized that the lack of influence of prey availability on carnivore richness might be a consequence of a spatially wide availability of food resources, throughout the landscape matrix.

Conservation implications

Mammalian carnivores play a crucial role in ecosystems, being organisms in the highest levels of food chains (e.g. Erlinge et al., 1983). Overall, our results suggest that landscape heterogeneity and fragmentation, as well as exotic forest plantations,

negatively influence carnivore richness within the BVL landscape; and reinforced the importance of riparian habitats to carnivores in this landscape matrix. Therefore, the conservation and enhancement of landscape connectivity in BVL patchy landscape can be regarded as vital components for biodiversity conservation, namely carnivores.

Riparian habitats act as corridors or keystone shelters that favour the carnivorous species and establish a net of hedgerows in the landscape matrix. Hence, the conservation and recovery of linear woody remnants around some watercourses, particularly those surrounded by open areas such as pastures, agricultural crops and wet systems should be a management priority in the BVL.

Moreover, attending to the vast extent of eucalyptus plantations, not only the study area but also all over Portuguese territory, the negative influence of this type of forest on carnivore assemblage raises conservationist concerns. Several authors had previously warned to this ecologic problematic in Mediterranean ecosystems (Zahn et al., 2009; Proença et al., 2010; Matos, 2011). Since most of the eucalyptus plantations are in private lands with commercial purposes, namely timber production, the intervention at this level is limited in the study area. Hence, conservation measures should be focused on the maintenance and recovery of the remnants of natural Mediterranean forest patches in the landscape matrix, such as riparian areas and *Bocage*.

By performing efforts towards the conservation of carnivores, and particularly, by protecting and enhancing the abovementioned habitats, the conservation of other species, and local biodiversity in general, is also targeted, since carnivores are often regarded as "umbrella species" (Caro, 2003; Kerley et al., 2003; Roberge and Angelstam, 2004), due to their ecological traits.

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Chapter 5

GENERAL DISCUSSION

5. GENERAL DISCUSSION

Baixo Vouga Lagunar, a heterogeneous costal wetland in north-western Portugal, represents one of the most biologically rich wetlands in Europe, supporting internationally important numbers of rare birds and plants (Marques and Ramos, 2006; Brito et al., 2010). On the other hand, comparatively, little is known about terrestrial mammals, namely small mammal and carnivore communities, and about species distributions in the different habitats within this heterogeneous wetland system.

In this study were identified eight small mammal species in the study area, including six rodent species (*Apodemus sylvaticus*, *Mus* sp., *Microtus lusitanicus*, *Microtus agrestis*, *Arvicola sapidus*, *Rattus norvegicus*) and two shrew species (*Crocidura* sp., *Sorex granarius*). Concerning the carnivore assemblage, six different species (*Vulpes vulpes*, *Mustela putorius*, *Mustela nivalis*, *Meles meles*, *Lutra lutra*, *Genetta genetta*) were identified, including most medium-sized species occurring in Mediterranean habitats in the Iberian Peninsula (e.g. Gomes, 1998; Mestre et al., 2007; Matos et al., 2009; Pita et al., 2009). Overall, the results showed that the BVL landscape provides habitat to a diverse terrestrial mammalian community. Hence, this study highlights the biological richness found in the BVL landscape (as also mentioned by Brito et al., 2010) and reaffirm its importance as a key element in maintaining regional biodiversity.

Understanding the distribution patterns and habitat preferences of the mammal fauna inhabiting a region is crucial to define complete and adequate management guidelines, and to develop and implement appropriate conservation priorities. In this study we aimed to: i) test the influence of habitat type, landscape composition and climate conditions on small mammal relative abundance and species richness; ii) investigate the influence of the landscape heterogeneity on small mammal abundance and richness; iii) determine which type of factors, namely vegetation features, human influence and/or prey availability (or combination of these) affect carnivore richness; and iv) identify keystone structures and/or limiting resources for the carnivore assemblage within the landscape matrix. The main findings of this study concerning terrestrial mammals in the BVL are:

i) Positive influence of wetlands habitats such as reed beds, rushes and marshland on small mammal fauna;

ii) Positive influence of freshwater lines and consequently riparian habitat on carnivore richness;

iii) Negative influence of the exotic forest on small mammal fauna and carnivore richness, and;

iv) Positive influence of landscape heterogeneity on small mammal fauna at broader-scale and, negative influence of landscape heterogeneity and fragmentation on carnivore richness.

5.1 KEYSTONE STRUCTURES

Several studies in heterogeneous landscapes reported that fauna diversity is closely linked to "keystone structures" (Lima and Gascon, 1999; Pita et al., 2009; Rosalino et al., 2009; Pereira and Rodríguez, 2010). These structures were defined as a "distinct spatial structure providing resources, shelter or 'goods and services' crucial for other species" by Tews et al. (2004). This study supports this theoretical context and allowed the identification of keystone features in the BVL, crucial for maintaining species diversity.

Wetland habitats and small mammals

Wetland habitats, such as reed bed, rush and marshland, seemed to favour small mammal fauna, thus suggesting that these habitats may be keystone structures to small mammals in this landscape matrix. The importance of these environments to small mammals has previously been demonstrated by several authors (Bowland and Perrin, 1993; Michelat and Giraudoux, 2006; Scott et al., 2008). These habitats, mainly reed bed, provide abundant and easily available food resources for rodents, as reed seeds (Canova and Fasola, 1991). Hence, the positive influence of these environments on small mammal fauna, namely rodents, probably reflects the general statement that food availability is one of the most important factors in small mammal persistence, limiting individual survival and reproduction and population dynamics (Hansson, 1979; Algelstam et al., 1987; Boutin, 1990; Gray et al., 1998; Ecke et al., 2001). This result agrees with data from a previous study developed in an Estonian coastal wetland (Scott et al., 2008).

Furthermore, the positive influence of rice field on some rodent species may reflect the same assumption, since rice grains could represent food supply to these granivore species (Singleton et al., 2005).

Riparian galleries and carnivores

Despite of the impoverished condition of the riparian habitat found in the study area, the results of this study suggest that freshwater lines (small stream and rivers, except *Bocage* waterways) and consequently, riparian galleries can be qualified as a keystone structure to mammalian carnivores in this heterogeneous wetland region. The importance of riparian areas for biodiversity, providing shelter and functioning as corridors for some species, has previously been demonstrated by several authors (Lima and Gascon, 1999; Virgós, 2001; Rondinini et al., 2006; Matos et al., 2009; Pereira and Rodríguez, 2010). This could be explained due to higher resource availability found in these environments, since riparian areas provide freshwater and shelter, while also promoting external temperature regulation (Rondinini et al., 2006; Matos et al., 2009; Pita et al., 2009; Rosalino et al., 2009; Pereira and Rodríguez, 2010; Santos et al., 2011). The results obtained in this study reinforce the importance of riparian corridors for carnivores in highly heterogeneous and deforested areas, since vegetation associated with streams may be the only remaining woodland providing shelter (Virgós, 2001), while simultaneously enhancing landscape connectivity (Červinka et al., 2013).

5.2 FOREST

Mediterranean forest patches are known as an important habitat for terrestrial mammal conservation, providing secure shelter to carnivores and cover protection from predators to small mammals (Virgós and Casanovas, 1999; Virgós, 2001; Rosalino et al., 2011a,b). However, forest patches in the study area are mainly plantations dominated by exotic tree species such as eucalyptus (*Eucalyptus* sp.). In general, the results showed that terrestrial mammal richness was not favoured by forest cover. The negative effect of exotic forest on mammalian community agrees with the fact that monocultural forestry plantations reveal lower fauna diversities, when compared to native forests (Carey and Johnson, 1995; Saitoh and Nakatsu, 1997; Marsden et al., 2001; Proença et al., 2010; Matos, 2011). Forestry plantations, namely the ones managed for timber production, are greatly simplified habitats for animals, and may not provide adequate conditions for fauna subsistence or establishment, such as understory vegetation, nesting sites or food resources (Marsden et al., 2001; Zahn et al., 2009). Nevertheless, high values of *A. sylvaticus* abundance, a generalist species, were recorded in the forest. Overall, these

results agree with the fact that monocultures may favour dominant species, impoverishing the mammal community in terms of species diversity (Saitoh and Nakatsu, 1997; Matos, 2011).

5.3 LANDSCAPE HETEROGENEITY AND FRAGMENTATION

The habitat heterogeneity hypothesis initially developed by MacArthur and MacArthur (1961) states that an increase in the landscape heterogeneity leads to an increase in species diversity, due to the greater number of available niches. In fact, heterogeneous environments have been associated to a positive influence on small mammal fauna (e.g. Bowland and Perrin, 1993; Ecke et al., 2002; Scott et al., 2008; Fischer et al., 2011; Sponchiado et al., 2012), and also on carnivore species (Mestre et al., 2007; Pita et al., 2009; Pereira et al., 2012).

Concerning small mammal fauna, the fine-scale of the landscape heterogeneity did not seem to influence small mammal abundance and richness. In general, small mammal abundance did not appear to be significantly different in identical habitat patches throughout the landscape matrix, and edge length and number of habitats (heterogeneity variables) did not reveal to be significantly influent on the small mammal abundance and richness. However, the results suggest that, at the landscape-scale, the habitat mosaic of BVL favoured the small mammal fauna. In fact, several small mammal species revealed to be differently influenced by the distinct habitats and consequently their distribution fluctuated through the patchy landscape.

Regarding the carnivore assemblage, edge length did not favour carnivore richness. Since the study area is characterized by many small patches of diverse habitats, edge length can be considered as a measure of both fragmentation and heterogeneity of this particular patchy landscape. Hence, the results suggest that the landscape heterogeneity, and the associated fragmentation, did not enhance carnivore community. This negative effect may be a consequence of the disruption of key biological processes such as dispersal and resource acquisition caused by fragmentation (Saunders et al., 1991). The BVL landscape is characterized by a spatial discontinuity, dominated by open habitats. Additionally, the lack of available corridors and linear structures that enhance landscape connectivity may restrict the movement of organisms and disrupt ecological processes across the landscape, impoverishing carnivore assemblage. Once more, these

findings reinforce the importance of linear structures, as riparian galleries, in the landscape matrix of BVL, by enhancing connectivity, as mentioned above.

5.4 CONSERVATION IMPLICATIONS

This study reinforced the importance of BVL region to wildlife, since it was found a very diverse mammal community, and emphasizes the need to develop adequate management guidelines and implement appropriate conservation priorities. In fact, the main findings of this study have profound implications for nature conservation and biodiversity management, as detailed bellow, in the fragmented landscape of BVL.

The conservation and recovery of linear woody remnants around some watercourses (small streams and rivers), particularly those surrounded by open areas such as pastures, agricultural crops and wet systems, should be a management priority in the BVL. This is of particular importance since these habitats act as corridors or keystone shelters, that favour the carnivorous species and establish a net of hedgerows in the landscape matrix.

The maintenance of wetland habitats is crucial to the regional biodiversity, since small mammals, key organisms in the trophic chain, were favoured by these environments. Nevertheless, the importance of wetlands is not confined to the biodiversity harboured. These shallow-water ecosystems provide valued functions and services, such as productivity, water quality improvement, flood abatement, and carbon sequestration (Zedler and Kercher, 2005). Thus their economic value is particularly high, being mandatory their conservation and restoration (Zedler, 2000; Zedler and Kercher, 2005).

On the other hand, attending to the vast extent of eucalyptus plantations not only the study area, but also all over the Portuguese territory, the negative influence of this type of forest on carnivore assemblage raises other conservationist concerns. Several authors had previously warned to this ecologic problematic in Mediterranean ecosystems (Zahn et al., 2009; Proença et al., 2010; Matos, 2011). Since most of the eucalyptus plantations are in private land, and are used to commercial proposes, namely timber production, the intervention at this level is limited in the study area. Hence, conservation measures should be focused on the maintenance and recovery of the remnants of natural Mediterranean forest patches in the landscape matrix, such as riparian areas. *Bocage* is one of the few environments in the wider landscape of the BVL with autochthonous woody vegetation (e.g. *Salix atrocinera*, *Alnus glutinosa*, *Quercus robur*). Moreover, in Portugal

the distribution of this habitat is limited to the BVL region and, besides this area, it only occurs in southern France and northern England (Brito et al., 2010). Hence, since it is a rare habitat with important implications for regional biodiversity, its conservation should also be a priority target in this region.

Besides the importance of particular habitat elements in the landscape matrix, it should be noted that conservation and management efforts in the BVL patchy landscape will often need to consider characteristics of the surrounding landscape, since landscape heterogeneity plays an important role, both positive and negative, in the small mammal and carnivore distributions, respectively.

5.5 FURTHER WORK

This study provides important information about the terrestrial mammalian community (small mammals and carnivores) in the BVL region. Wetlands and riparian areas were found as key habitat to small mammal fauna and carnivore assemblage, respectively, in the heterogeneous landscape. Furthermore, was found a negative influence of BVL landscape heterogeneity and fragmentation on carnivore richness, as well as exotic forest plantations, and contrasting a positive influence of landscape heterogeneity on small mammal fauna. However these conclusions arise many other questions. Thus, further studies in the region should investigate:

i) The factors associated to the small mammal microhabitat selection within wet systems, helping to identify the role of wetlands in the conservation of small mammal populations and their predators in this Mediterranean landscape matrix;

ii) Which factors affect mammalian carnivore use of riparian ecosystems (e.g. prey, water, shelter), and their importance to carnivore assemblage taking into account the characteristics of its surroundings;

iii) The actual effect of riparian vegetation in the landscape connectivity, since landscape heterogeneity did not favour carnivore richness; and,

iv) How some carnivore species use the landscape matrix, namely species that are known to use linear structures, such as freshwater lines with riparian vegetation (e.g. *Mustela putorius*). Specifically, by using tracking techniques (e.g. radio-telemetry), should be examined its home range, activity patterns and habitat selection at different scales (individual and population). This information may be important to the development of more efficient conservation plans. Despite the fact that carnivores are generally considered to

be part of the same ecological guild, there is a general consensus that, in a given ecosystem, distinct species may respond differently to spatial structures (Andrén, 1994; Crooks, 2002; Tews et al., 2004). Since our study focused on carnivore richness, more detailed information may be particular important to carnivore species with important conservation status, such as *Mustela putorius*. This species is classified as Least Concern by the IUCN (Fernandes et al., 2008), but its conservation status in Portugal is Data Deficient, since there is not enough data to make an assessment of its risk of extinction (e.g. population trends) (Cabral et al., 2005). Moreover, this study did not investigate all human influence variables present in the study area. Some descriptors, such as direct persecution (e.g. illegal hunting, killing or capturing of wild animals) are difficult to access and quantify. However, these variables (e.g. poaching) can be relevant to the carnivore species occurrence in the study area. Nevertheless, using tracking techniques (as suggested above) may be enable to obtain information about the relation between the studied animals and human activities, namely direct persecution.

5.6 REFERENCES

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